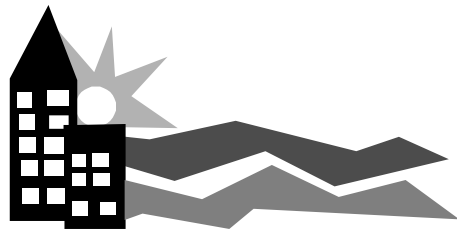


# Energy-Efficient Ventilation for Apartment Buildings



Rebuild America



# Preface

Welcome to the Rebuild America Guide Series. This series of technical and business manuals is designed to meet the real-life needs of the Rebuild America community partnerships. These Guides provide clear and practical information on issues related to energy-efficient building retrofits. Each Guide will help the partnerships make educated decisions as they move through the retrofit process. The Rebuild America Guide Series is one of the products and services that the U.S. Department of Energy provides to America's communities to help them attain more efficient and affordable buildings.

*Energy-Efficient Ventilation for Apartment Buildings* has been written for apartment building owners, managers, and organizations in the Rebuild America program who are considering energy-efficient ventilation projects. This Guide, prepared by the Lawrence Berkeley National Laboratory (LBNL) provides definitions, descriptions, and approaches for diagnosing ventilation needs and for designing energy-efficient systems that will achieve both short and long-term benefits.

The Rebuild America Program recommends that its partners incorporate ventilation strategies into their projects in order to maximize building performance, productivity, air quality, and energy efficiency. This Guide details these benefits with respect to low-rise and high-rise apartment buildings.



# Acknowledgments

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Much of the material on ventilation system design and maintenance is adapted from “A Guide to Energy Efficient Ventilation,” edited by **Martin Liddament**, published by the Air Infiltration and Ventilation Centre, Great Britain, 1996.



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# List of Acronyms

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPR	Envelope Permeability Ratio
ESCOs	Energy Service Companies
HDD	Heating Degree Day
HVAC	Heating, Ventilation and Air-Conditioning
NKB	Nordic Committee on Building Regulations
NPL	Neutral Pressure Level
VHC	Volumetric Heat Capacity of Air
VPR	Vertical Permeability Ratio

# List of Units

PPM	Parts per Million
ACH	Air Changes per Hour
CFM	Cubic Feet per Minute
Pa	Pascals
m/s	Meters per second



# Introduction

This Guide is written to aid building owners, project managers, designers, architects, and engineers currently participating in the Rebuild America program. It provides definitions, descriptions and advice on the numerous factors that must be considered when designing, maintaining, and operating ventilation systems—whether for retrofit or new construction. It should be used in conjunction with *Rebuild America's Community Partnership Handbook* which outlines eight important steps for planning and carrying out a community-wide, energy-efficiency program. Steps number 5 and 6, (see **Steps for Your Partnership**, page 2) indicate that development of an action plan and evaluation of individual buildings are integral steps required to secure successful implementation of ventilation strategies.

Rebuild America strongly encourages its partners to incorporate the information found in this Guide into their ventilation retrofit projects. Combining energy-efficient measures with correct installation, operation and maintenance of ventilation equipment will ensure optimum benefits for all concerned. The diagnostic, improvement, and maintenance strategies listed in this Guide provide a basis to assist Rebuild America partnerships in making cost-effective and energy-efficient decisions.

## Why is Good Ventilation Important?

In order to succeed in today's apartment-rental marketplace, apartment-building owners must keep costs low while maintaining or improving tenant comfort and building integrity. Adequate building ventilation is fundamental to human health and comfort. Proper ventilation includes sealing the building envelope to reduce uncontrolled air leakage (infiltration) and ensuring that all ventilation efforts complement, rather than sabotage, each other. Correct air pressure and airflow helps assure a balanced building temperature and better indoor air quality.

## Steps for Your Partnership

### 1 Form Your Partnership

Make a commitment to significantly reduce building energy use and cost in your community, and identify the organizations who will work together with you.

### 2 Collect and Examine Data

Define your targeted building stock and collect basic data on building characteristics, energy use, and energy costs.

### 3 Conduct Initial Screening

Conduct a simple screening of your targeted buildings to identify a candidate list of buildings that represent the best opportunities for energy savings.

### 4 Define Financing Options

Take a first look at costs, savings, and financing issues; develop rough cost estimates and funding options for both management and capital costs.

### 5 Develop an Action Plan

Define a practical action plan with your partners, using everything above to outline clear program goals along with management, financing, marketing, and business strategies to achieve them.

### 6 Evaluate Individual Buildings

Perform detailed energy audits on your best candidate buildings to define specific efficiency measures, their costs, and their savings potential.

### 7 Implement Your Program

Design, finance, install, and commission energy-efficiency retrofits. Consider holding community-wide education and training programs, and look into changes to codes and standards that can help your efforts.

### 8 Verify and Report Results

Verify and document the savings you have achieved in order to enhance the credibility of your program, improve it, and tell others about your results.

#### Planning Ventilation— Improvement Strategies

- Look into your options
- Plan your strategy for action
- Evaluate your potential for cost savings

## What DOE Will Do to Help

When you joined Rebuild America, DOE formally recognized your commitment and assigned a Program Representative to be your primary point of contact for assistance. Your Program Representative is available to assist you in developing and carrying out your ventilation-improvement strategies.

You can access a broad range of guidance materials, technical information, analytical tools, topic-specific workshops, and expert and peer contacts through your Program Representative and DOE's support network of national laboratories. As individual partnerships complete retrofit projects, their experience is made available to all so that other partnerships can benefit. Partnership case studies are displayed on the Rebuild America web-site at [www.eren.doe.gov/buildings/rebuild/](http://www.eren.doe.gov/buildings/rebuild/).

## How to Use this Guide

This Guide contains general recommendations for developing ventilation strategies for apartment buildings. The discussions in each chapter can be applied to both low-rise and high-rise apartment buildings.

### Chapter 1: What is Ventilation?

Chapter 1 provides a detailed discussion of ventilation needs for both new and existing building stock. Three main areas are discussed: ventilation needs, new and existing apartment-building construction and building airtightness. By focusing on building integrity and structure issues, this chapter helps apartment owners evaluate ventilation requirements and determine energy-efficient solutions in the context of both new and existing building stock.

### Chapter 2: Components of Airflow

This chapter helps the reader put boundaries around the scope of the ventilation project. By focusing on the ventilation needs in the context of various apartment-building designs, project managers can determine the extent of ventilation and energy-efficiency improvements required. Project managers may also find this information useful when interacting with various consultants.

### **Chapter 3: Ventilation Retrofit Requirements**

Chapter 3 provides a general discussion of the principles underlying ventilation in apartment buildings. Temperature dynamics, airflow, air pressure, building construction and climate-related interactions within a building are all described in this chapter. Options for improving ventilation are discussed and information is provided on the various retrofit strategies and their applicability to different conditions and structures.

### **Chapter 4: Causes and Diagnostics of Ventilation**

Chapter 4 explains the physics of apartment ventilation in relation to design, with discussion of building construction, airflow patterns, pressure differences and climate related considerations. Diagnostic methods are defined in order to indicate the type of ventilation strategies required.

### **Chapter 5: Designing a Ventilation Retrofit**

This chapter contains recommendations for improving ventilation in both high and low-rise apartments and also recommendations for optimizing natural and mechanical ventilation strategies. Discussion of climate, building configuration, first costs, and potential energy savings all help to determine specific retrofit options.

### **Chapter 6: Choosing a Ventilation Strategy**

Discusses recommendations for natural and mechanical ventilation strategies that may be employed in both high and low-rise apartment buildings. Descriptions of exhaust-only, supply-only and balanced-ventilation components used in apartment buildings are offered along with detailed options.

### **Chapter 7: Operating and Maintaining Ventilation Systems**

The final chapter emphasizes the need for regularly scheduled maintenance to ensure efficient operation, good air quality and long system life.

## **Appendix A: Apartment Building Ventilation Assessment Protocol**

This appendix describes how to perform a general apartment building ventilation audit, and includes an assessment protocol, building survey, tenant survey, and other information.

## **Appendix B: Frequently Asked Questions**

This appendix answers some of the more commonly posed questions regarding apartment ventilation.

Lastly, a glossary is included at the end of the Guide for easy reference.





# Chapter 1: What is Ventilation?

## Overview

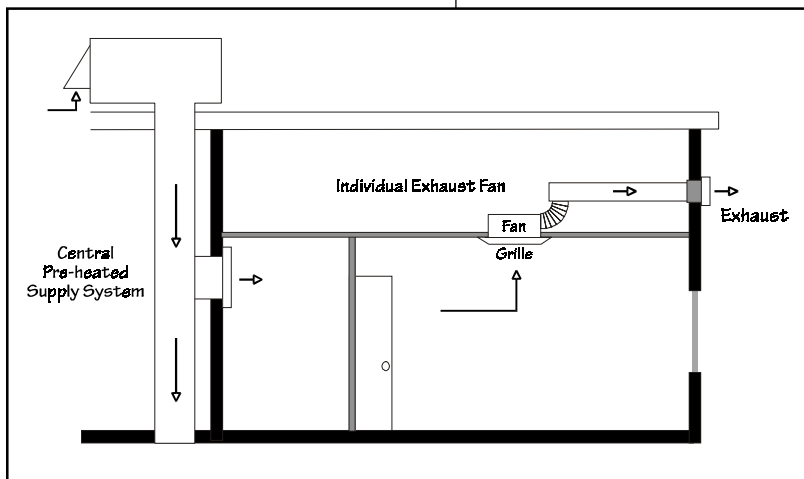
Ventilation is a necessity for the health and comfort of occupants of all buildings. Ventilation supplies air for occupants to breathe and removes moisture, odors, and indoor pollutants like carbon dioxide. Ventilation design for apartment buildings is inherently more complex than what is required for single-family homes. Most apartments have limited exposure of walls and windows to the outside environment. Additionally, the natural physical forces that move air are more pronounced in taller buildings. This includes “infiltration” and “exfiltration”—the unintentional and uncontrollable flow of air through cracks and leaks in the building envelope. There are two primary forms of intentional ventilation—natural and mechanical. Low-rise buildings (3 stories and under) often utilize “natural” ventilation, that is, air supplied and vented through operable windows. High-rise buildings (over 3 stories) often use “mechanical” ventilation systems in the form of fans, air-inlets, ducts and registers, but may also rely on operable windows when mechanical systems fail to provide adequate ventilation.

Sufficient ventilation is necessary for occupant comfort and maintaining building integrity. Ventilation air is needed in all habitable spaces including common areas used for circulation, such as hallways and stairwells. Ventilation may also be needed in lobbies, storage spaces, parking areas, janitor’s offices, and mechanical and equipment rooms.



## Natural and Mechanical Ventilation

**Figure 1: A Typical Apartment Building's Mechanical Ventilation System**



Most residences rely exclusively on infiltration and natural ventilation strategies. The main drawback to these ventilation strategies is the lack of control. Unreliable driving forces can result in periods of inadequate ventilation followed by periods of over-ventilation which can cause excessive energy waste. Good design can provide some measure of ventilation control, but normally it is necessary for the occupant to adjust ventilation openings to suit demand. When infiltration and natural ventilation systems are inadequate (as determined either by code or experience), mechanical ventilation should be installed.

Mechanical ventilation systems are capable of providing a controlled rate of air exchange and should respond to the varying needs of occupants and pollutant loads, irrespective of climate vagaries. While some systems filter supply air, others have provisions for energy recovery from the exhaust air stream. In some countries, especially in parts of Canada and Scandinavia, mechanical systems are being incorporated into virtually all new apartment building construction and are also being included in many building renovation programs.

The typical apartment building's mechanical ventilation system has a central supply system which conditions the air (e.g., heats, cools, and filters) and individual exhaust fans serving each apartment (See Figure 1).

Both natural and mechanical ventilation systems must be installed and operated correctly to provide proper ventilation. Decisions on whether to provide natural and or mechanical supply-only, exhaust-only, or both supply and exhaust will depend on several ventilation-related factors, including:

- Weather
- Building configuration
- Access to ventilation
- Tenant behavior, and
- Cost.

## Determining the Amount of Ventilation Needed

Too little ventilation may result in poor indoor air quality, while too much may cause unnecessarily higher heating and cooling loads. Ultimately, the ventilation rate should be sufficient to maintain indoor air quality and comfort requirements. The required rate may change according to a building's occupancy patterns and the pollution and climatic changes in the surrounding environment. Therefore, provisions to control the rate of ventilation to meet the current prevailing demand are desirable. A typical ventilation design is based on each apartment's minimum calculated need (by volume or occupancy) which increases when air-borne pollutants are prevalent (See pages 15-17 in Chapter 2). To minimize the need for additional ventilation, individual pollution sources, such as combustion equipment, should be identified and removed from the occupied space or vented at the source.

Building occupants, building code officials, and energy service companies (ESCOs) often approach the issue of adequate ventilation from vastly different perspectives. These stakeholder groups tend to choose specific ventilation strategies aligned with their perspective.

**Occupant Perspective** — From the occupants' perspective, adequate ventilation may be defined as whatever air is needed to remove odors and to provide a healthy and comfortable environment. Residents may not be aware of the importance of ventilation in reducing odorless pollutants—such as moisture or carbon monoxide—which may have an impact on their health and comfort. Residents who are responsible for their heating and or cooling bill will probably be more sensitive to the energy cost associated with ventilation. If residents are unhappy with existing mechanical ventilation systems, for reasons like noise from associated fans, drafts produced by high air velocities; the location of registers, or discomfort from ventilation temperature, they may turn off, or otherwise undermine the operation of their systems.

**Building Code Official Perspective** — From the building code perspective, adequate ventilation refers to that level of ventilation that protects the health and safety of its occupants. Most regions of the U.S. have building codes that specify ventilation levels for new buildings. Some regions have similar requirements for existing buildings. Such requirements or recommendations may cover ventilation

rates (ASHRAE Standard 62-1989), and thermal comfort (ASHRAE Standard 55). Building codes typically require operable, exterior window openings for certain rooms within the living space. If those rooms lack operable windows, mechanical ventilation is necessary. Bathrooms and kitchens, prime sources of indoor odor and moisture pollutants, are often located in windowless interior spaces and, therefore, require mechanical exhaust ventilation.

The amount of ventilation and or the size of operable windows is specified by the building codes in place at the time of construction. Accordingly, apartment buildings, built at various times over the past one hundred years, will have different ventilation rates based primarily on the codes in place at the time of their construction. Often the design ventilation rates for these older codes are much lower than those in current codes and standards. Even if properly designed according to the code in place at the time of construction, the ventilation systems in a given building may not be delivering the designed ventilation rate. Therefore, designing (or redesigning), implementing, and operating ventilation systems to provide the most current minimum recommended ventilation rates will typically provide higher levels of ventilation and indoor comfort.

**Energy Service Company (ESCO) Perspective** — An ESCo provides energy performance services for building owners. The ESCo's investment in retrofitting or otherwise achieving increased energy efficiency in a client's building leads to reduced energy bills. These energy savings are used to cover the ESCo's costs. While there are numerous opportunities for investing in improving the energy efficiency of apartment buildings, ESCos are often reluctant about such investments, especially in complex ventilation strategies, such as tightening the building envelope or working with previously installed mechanical ventilation systems. ESCos may be unwilling to finance ventilation retrofits due to legal liability concerns about pre-existing ventilation problems and the significant length of time required for recovering investments in older buildings with inadequate or non-functioning ventilation systems.

It may be a challenge for an ESCo to accurately determine what energy-saving measures will most profitably offset the costs of improving ventilation. Quick payback retrofit activities can sometimes offset the longer payback retrofits and provide a more comprehensive and integrated retrofit project with higher, long-term overall energy savings. Often, ESCos may ignore the long-term, more integrated retrofit projects—such as upgrading ventilation systems—and limit

themselves to gaining a quick return available from less complex, short-term projects. This practice, sometimes known as “cream-skimming,” is often profitable to the ESCo, although it can underutilize a building owner’s retrofit dollars. By implementing integrated retrofit projects, an ESCo and the building owner can maximize the overall total energy savings.

**Building Owner and Project Manager Perspective** — From a building owner’s perspective, adequate ventilation could be defined as the minimum airflow needed to maintain the soundness of a building and the health of its occupants at the lowest possible energy cost. Although each building manager will respond differently to complaints from occupants, it is always in the manager’s best interest to take steps to minimize building damage and adverse health and safety issues from moisture or other pollutants. Regular maintenance and upkeep will maintain the integrity of the building and retain building profitability and economic viability over the long run.

The ventilation-system designer, retrofit-project manager, or building owner must consider all of the options discussed above and make an informed choice about how much effort, time, and money will be put into an apartment building ventilation project.



# Chapter 2: Components of Airflow

## Overview

Building or project managers should endeavor to provide satisfactory ventilation via adequate supply and exhaust of air. Natural ventilation driven by wind and temperature differences is typically provided through windows. Mechanical ventilation is provided by ducts and registers, and is driven by fans. A satisfactory ventilation system will provide supply air with the following characteristics:

- Minimal impurities or pollutants
- Comfortable temperatures
- Low flow rate and reduced noise.

These characteristics are more likely to be found in ventilation systems that are well-designed, and in buildings that are sufficiently airtight.

## Airtightness

The term “airtightness” describes the resistance of the building envelope to the flow of air. The airtightness of a building is often specified as the amount of air leakage, in cubic feet per minute (cfm), at specifically defined pressures (e.g., 50 Pascals) or in terms of an equivalent leakage area determined from blower-door measurements (see page 37, Chapter 4). The rate of air exchange—the time in which a given enclosed space receives and or exhausts a complete change of air—is measured in air changes per hour (ACH). A target rate of air change per hour is 0.35. At this rate, all the air in the space gets replaced once every three hours.



Airtightness is affected by the airflow paths in the building. Leaks within the intended airflow pathways are of two general types; leaks in interstitial space (space between floors and walls) and leaks in the building envelope. These can be the result of any of the following:

- Architectural design choices (such as location of windows, balconies, elevators, lobbies, and the materials used)
- Cracks and openings where different materials come together (i.e., building tightness)
- Penetrations (including elevator shafts, plumbing cracks, and garbage chutes) that connect to the outside
- Connections between floors and apartments

Leakage sites provide pathways in which ventilated air unintentionally enters or leaves a ventilated space. The driving forces behind the volume of unintended airflow are temperature and pressure differentials in and around the building. Excessive or insufficient infiltration or exfiltration result from the joint effect of these two components.

The consequences of unintentional ventilation are:

- Wasted energy (and money) used in mechanical heating or cooling
- A general decrease in occupant comfort and or safety

Further discussions on the effects of airtightness appear in Chapter 5 of this Guide.



## Ventilation for Acceptable Air Quality

As discussed in Chapter 1, adequate ventilation is defined, from a building code perspective, as a level of ventilation that protects health and safety of occupants. The principle standard for ventilation in U.S. apartment buildings is that provided by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), Standard 62-89, Ventilation for Acceptable Indoor Air Quality. This industry standard was last revised in 1989 and is often adopted by local building codes for use in apartment buildings.

The standard stipulates that a minimum outside air change rate should be based either on the volume of the space to be ventilated or on the number of occupants. It states that each apartment must allow a minimum of 0.35 air changes per hour (ACH) per cubic foot of ventilated space, or 15 cubic feet per minute (CFM) per person, whichever of the two is higher. See the next page for a worksheet designed to assist users in calculating the minimum recommended air change rates for an apartment.

## Worksheet for Determining Minimum Recommended Ventilation Rates

The recommended amount of ventilation air that should be available can be calculated either by measuring the number of occupants living in an apartment or by the total volume. Use the following steps to calculate the minimum recommended ventilation rate.

### A. Minimum recommended airflow rate based on VOLUME:

1. Calculate the volume of the apartment:

$$\frac{\text{Floor Area (ft}^2\text{)}}{\text{Ceiling Height (ft)}} \times \text{Ceiling Height (ft)} = \text{Volume (ft}^3\text{)}^a$$

<sup>a</sup>(if an apartment has more than one ceiling height, calculate the volume for each individual apartment and add them together to get the total apartment volume)

2. Calculate the amount of air that passes through the apartment. Assume the air change rate is 0.35 air changes per hour (ACH).

$$\frac{\text{Volume (cfm)}}{\text{Air changes per hour divided by number of minutes in one hour}} \times \frac{0.35}{60} = \text{Airflow rate (cfm)}$$

### B. Minimum recommended airflow rate based on OCCUPANCY:

1. Write in the number of bedrooms, add one and multiply by 15 cfm:

$$\left( \frac{\text{Number of Bedrooms}}{\text{Airflow rate (cfm)}} + 1 \right) \times 15 \text{ cfm} = \text{Airflow rate (cfm)}$$

2. Write in the expected number of occupants and multiply by 15 cfm:

$$\left( \frac{\text{Number of Occupants}}{\text{Airflow rate (cfm)}} \right) \times 15 \text{ cfm} = \text{Airflow rate (cfm)}$$

3. Write the larger of B.1. and B.2. in the blank below. This is the minimum recommended airflow rate, based on occupancy.

\_\_\_\_\_ cfm(occupancy)

Write the larger of A.2. or B.3. in the box provided.

The minimum recommended airflow rate to be provided for this apartment is  cfm.

# Discussion

## Determining Minimum Recommended Ventilation Rates

Assuming an occupancy of two people in a one-bedroom apartment with a floor area of 800 ft<sup>2</sup>, and an 8-foot ceiling height, the worksheet on page 16 will produce the following results:

- Airflow Based on Volume—Using the calculation for airflow rate based on volume, the necessary airflow is 37 cfm or  $(800 \text{ ft}^2 \times 8 \text{ ft} \times 0.35 \text{ ACH} / 60 \text{ min})$ .
- Airflow Based on Occupancy—Using the calculation for airflow rate based on occupancy, the necessary airflow is 30 cfm for both the per person and per bedroom scenario or  $(2 \text{ bedrooms or } 2 \text{ persons} \times 15 \text{ cfm})$ .

Since the larger of the two values (volume-based or occupancy-based) should be used when planning a ventilation strategy, the minimum recommended airflow rate to be provided will be 37 cfm from the “Airflow Based on Volume” method.

Caution should be used when determining an occupancy-based ventilation rate, as in some instances, the “number of bedrooms + 1,” will underestimate the number of occupants, and therefore, the amount of total ventilation necessary. Use the occupant calculation if the number of occupants is greater than “number of bedrooms + 1.”

In a smoking environment, the ASHRAE parameters may not provide sufficient ventilation to safeguard the general health standards that the above calculations are meant to maintain. In New York State, the State Weatherization Program requires twice the recommended ACH for apartments with smokers, and encourages the installation and use of mechanical ventilation systems.



# Chapter 3: Ventilation Retrofit Requirements

## Overview

Many apartment buildings have significant ventilation problems that should be corrected whether or not other energy-saving retrofits are planned. However, it is often more cost-effective to retrofit a ventilation system during a general retrofit project than as an isolated endeavor.

When addressing ventilation problems, the challenge for building owners is knowing how to best provide ventilation without wasting energy. Likewise, the challenge for ESCos or other contractors is often whether enough savings can be generated from other aspects of the energy retrofit to pay for the costs of necessary ventilation work.

## Why Code Is Not Enough

When planning a retrofit, it is necessary to study the interrelated effects of temperature, pressure, and ventilation systems on airflow. Although building codes address ventilation needs, they are not necessarily foolproof. Experienced ventilation researchers have noted that:

- An apartment designed to code may not necessarily be built to code
- An apartment designed and or built to code may not necessarily be operating to code
- An apartment designed, built, and operating to code still may not have adequate ventilation.<sup>1</sup>

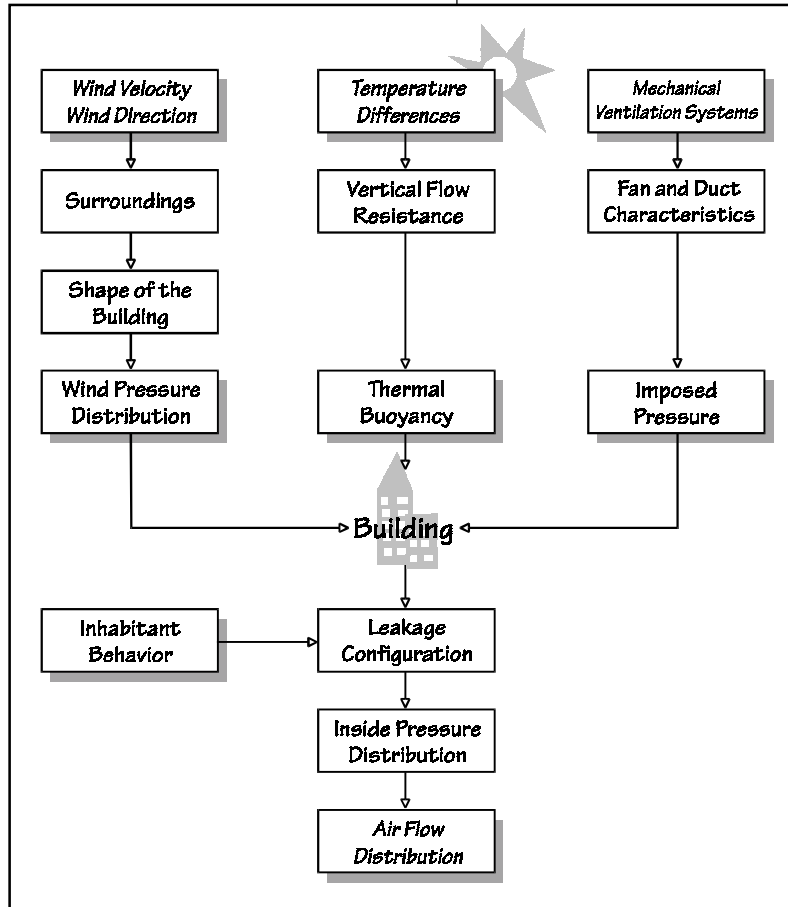
Providing proper and sufficient ventilation requires a “whole building” approach. This is a many faceted process that requires an integrated approach to a building system’s design, installation, and operation. When diagnosing ventilation problems the interrelation between the major factors in Figure 2 (page 20) depict how wind, temperature, and mechanical ventilation systems influence the airflow distribution in a building.

<sup>1</sup> Tohanika, 1996.



**Figure 2: Factors Influencing Airflow Distribution in Apartment Buildings**

## Planning Ventilation Strategies



The following eight provisions are provided to ensure that retrofit-ventilation strategists overcome the problems inherent to the building ventilation planning process:

- ☐ Understand the role of energy efficiency in ventilating activities
- ☐ Plan for ventilation system distribution and coverage
- ☐ Keep occupant comfort, well-being, and activities in mind
- ☐ Understand climate and ventilation-related interactions
- ☐ Identify potential sources of indoor pollutants
- ☐ Be aware of air pollutants from the local environment
- ☐ Understand the role of building construction in airtightness and building integrity
- ☐ Design ventilation strategies for different building types

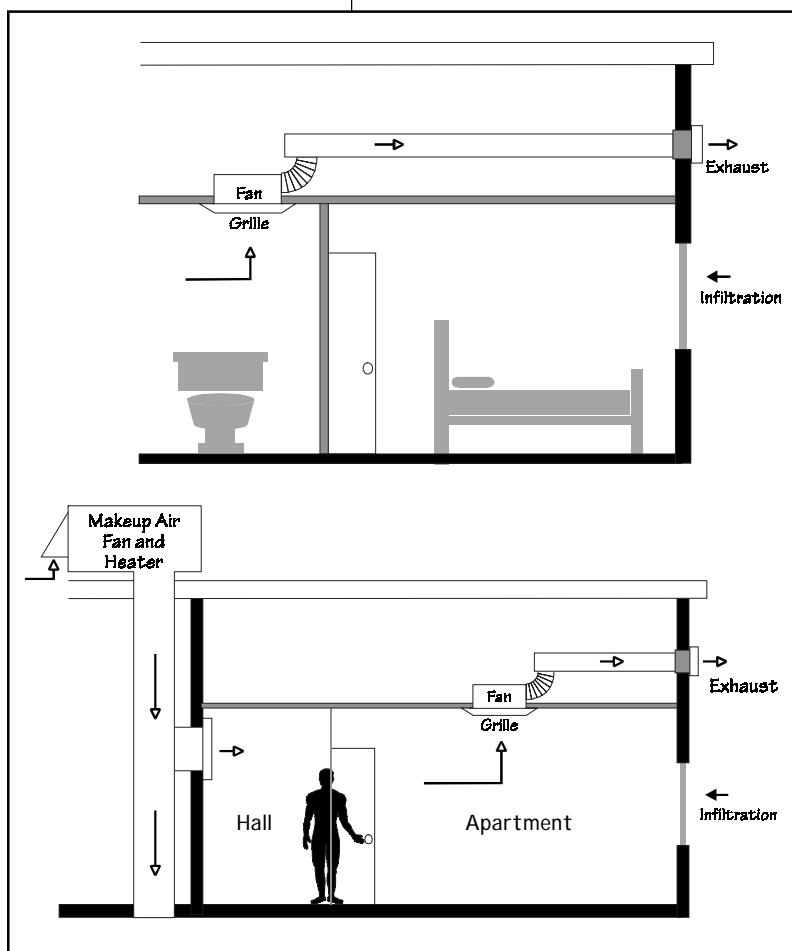
- ☐ **Understand the role of energy efficiency in ventilating activities**—All ventilating activities require a certain level of energy consumption and all have costs associated with this energy use. An additional cost may be incurred in providing sufficient ventilation to bring the building up to habitable conditions. In apartments where infiltration and operable windows already deliver some ventilation, the amount and cost of necessary mechanical ventilation is buried in the overall building space conditioning loads and costs. This ventilation-related energy liability can be offset by applying energy conservation methods to the whole building, including envelope tightening, infiltration reduction, and energy-efficient ventilation strategies (e.g., energy-efficient motors, energy-recovery ventilation). Building-tightening efforts will reduce infiltration and, correspondingly, provide energy-saving opportunities.

As infiltration is reduced through building tightening, airflow paths throughout the building will change, possibly creating greater imbalances between ventilation rates in different units. In such cases, alternate ventilation strategies must be explored to ensure that sufficient ventilation is provided to each apartment. Correctly designed and installed mechanical ventilation systems will produce more consistent and well-distributed ventilation than can infiltration. Often the energy savings realized through whole-building tightening and other energy conservation measures can be used to offset other ventilation costs during a ventilation retrofit.

**Plan for ventilation system distribution and coverage**—Basic building codes require that ventilation—in the form of operable windows or mechanical ventilation in spaces where windows are not present—be supplied to every apartment in a building. Mechanical exhaust ventilation is usually located only in the kitchen and or bathroom. Since closed doors between bedrooms and other parts of an apartment may prevent adequate ventilation throughout an apartment, either natural or mechanical supply inlets should be provided into these rooms. Figure 3 depicts the siting of various ventilation strategies, with exhaust from the bathroom and kitchen fans and supply from both infiltration and ducted make-up air provided to hallways and the apartments. [Note: In the lower half of Figure 3, the pressurized air from the hallway provides ventilation air to the apartment.]

**Keep occupant comfort, well being, and activities in mind**—Various ventilation codes and standards set ventilation recommendations and requirements for living spaces. In selecting, designing, and implementing ventilation strategies, designers should determine how the ventilation systems will best meet the comfort and operational needs of the occupants.

**Figure 3: Mechanical Ventilation System Locations**



Occupants play a very important role in determining the success of various ventilation strategies. Occupants may intentionally or unintentionally employ any number of mechanisms that may increase or decrease the need for ventilation. These include the following:

- Opening or closing windows due to heat or cold
- Keeping windows closed to avert the threat of crime or violence
- Being physically unable open windows due to location or construction
- Introducing excess moisture and pollutants from cooking, showering, drying clothes, or smoking.

When occupants open windows, they not only influence the ventilation in their apartments, but also in neighboring apartments. There is usually less effect between apartments on the same floor, but there can be an increase in infiltration in downstairs apartments when upstairs occupants open their unit's windows. Making efforts to compartmentalize and seal airflow paths within apartments, while also ensuring adequate ventilation, can help reduce this effect.

In some cases, occupants may deliberately block ventilation by taping over registers and vents or by putting blankets and towels against a door that has a large undercut, in order to counteract one or more of the following:

- Excessive heat or cold
- Noise
- Light
- Insects
- Cooking moisture and odors from other apartments
- Cigarette smoke from other apartments
- Excessive velocity of air supply.

People may experience discomfort from the movement of air, depending on the temperature and velocity of the air and what part of their body experiences the draft. Even relatively slow movement of air with a temperature



below 70°F can be uncomfortable. Heating the supply air and/or introducing it outside of the occupied zone will allow supply air to mix with room air and minimize discomfort.

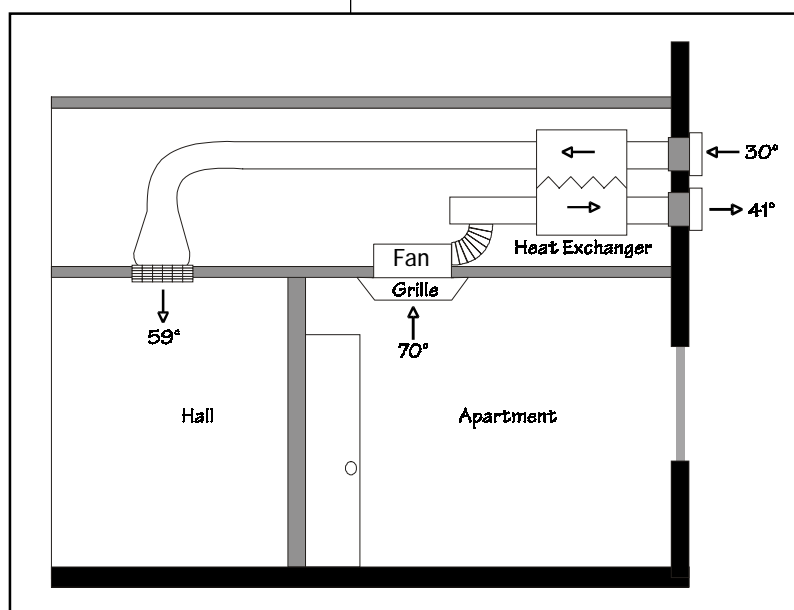
To ensure the success of ventilation strategies, the ventilation systems must be straightforward and easy to operate by building management and occupants. Further, adequate mechanical ventilation must be supplied in cases where occupants could be exposed to indoor or infiltrated pollutants that are odorless and colorless, such as carbon monoxide.

**□ Understand climate and ventilation-related interactions**—Depending on the local climate and the location of the building, supply air may need to be heated or cooled, filtered, (de)humidified, and distributed throughout the building. Climate has a significant impact on the choice of ventilation strategies.

In general, the more complex ventilation system is needed in buildings located in more severe climates. Milder climates often necessitate using only natural ventilation strategies, while mechanical systems or mechanical systems with “energy-recovery measures”<sup>2</sup> as depicted in Figure 4, at right, may be necessary to optimize energy efficiency in extreme climates.

Special attention is needed to determine solutions for the moisture and temperature conditions of hot and humid climates, as described in further detail in Chapter 4.

**Figure 4: Mechanical Ventilation System with “Energy Recovery” Measures**



<sup>2</sup> “Energy recovery measures” include the use of heat exchangers.

- **Mild climate.** Mild climates are typified by a minimal need for mechanized heating or cooling, with an annual heating degree day (HDD) value<sup>3</sup> of less than 3600. Ventilation heat loss is largely insignificant, and therefore the need to restrict ventilation flow is marginal. In this type of climate, it may be difficult to justify using complex ventilation systems. In a mild climate, airtightness is not essential, and air infiltration may not be a significant concern for many buildings. Opening windows may provide satisfactory ventilation except when the outside environment is noisy or polluted.
- **Moderate climate.** An HDD range of between 3600 to 5400 is common in moderate climates. Space heating or cooling (especially for small- to medium-sized buildings) is unnecessary for large parts of the year. High rates of air exchange are possible by opening windows during milder periods. Good building design and control of internal heat loads should minimize the need for mechanical cooling in all but large buildings or those exposed to polluted or otherwise stressful outside environments. Energy-saving measures tend to have prolonged cost-recovery periods due to the short seasonal need for heating and cooling.
- **Severe climate.** An HDD range of 5400 and or over 2000 annual cooling degree-days is common in severe climates. These climates include extended cold winters and or excessively hot summers. Conditioning loads are significant, resulting in seasonal peaks in energy demand. Mechanized cooling often cannot be avoided in severe climates because outside temperatures and humidity levels may be high. Building structures must be airtight and excess ventilation minimized to conserve conditioned air. Eliminating internal pollutants can help reduce the need for excessive ventilation. Sensible and latent heat recovery strategies are more likely to be energy and cost-efficient than in milder climate zones.

- **Identify potential sources of indoor pollutants**—Ventilation is most successful when it incorporates a strategy for dealing with indoor pollutants such as carbon dioxide, odors, and moisture (from cooking, washing, and clothes drying). Other indoor pollutants, which should be dealt with separately, include combustion products (such as carbon monoxide), tobacco smoke, and organic emissions from furnishings and fabrics. Such pollutants must be exhausted either at their sources or as part of a general ventilation strategy.

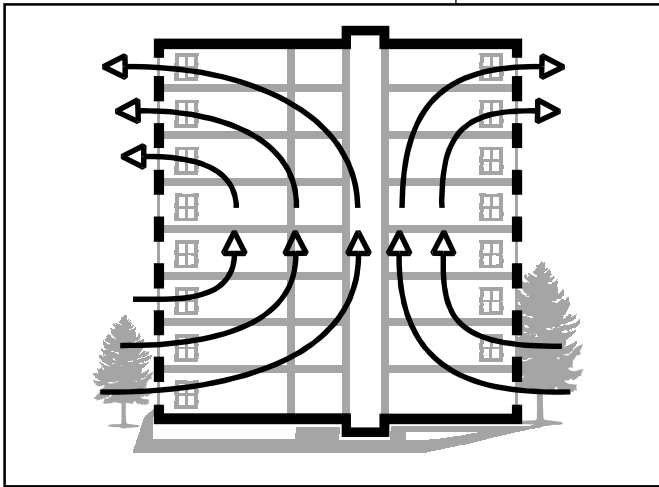
<sup>3</sup> Heating Degree Day (HDD) is the yearly sum of the difference in the average daily temperature and a 65°F base temperature, whenever the outside temperature is below 65°F.

Combustion appliances such as gas furnaces and gas water heaters need to be physically isolated from the living spaces to prevent backdrafting. Backdrafting refers to combustion pollutants that do not “draft” up the flue, but rather flow down the flue and into the apartment containing the combustion appliances, due to negative pressures in the apartment. Independent air supply is necessary for combustion equipment to vent properly, and should be supplied through either mechanical or natural means. The ductwork must be well connected to the appliance to prevent spillage and leakage of smoke and other gases into the apartment.

❑ **Be aware of air pollutants from the local environment—** The local outdoor environment further influences how natural and mechanical ventilation is designed and installed. Heavily industrialized and inner city locations, rural areas, and adjacent buildings all impact the choice and implementation of ventilation strategies.

- **Heavily industrialized and inner city locations.** Excessive vehicle emissions and industrial pollutants hurts the air quality in these areas. Ventilation systems might, therefore, need to incorporate some form of filtration to remove particulates, gases, and odors. When outside noise from passing traffic is excessive, occupants may not be willing to open windows for ventilation.
- **Rural areas.** Although apartment buildings are rarely found in rural areas, when present, they provide a special set of environmental air quality challenges. Rural areas may include high pollen concentrations, fungal spores, pesticides, and the by-products from agricultural burning. Air-filtration systems may be necessary for some apartment buildings to assist individuals who are hypersensitive to these pollutants. Because of high wind speeds in exposed areas, efforts must be taken to reduce cold drafts and air leakage.
- **Adjacent buildings.** Adjacent buildings can create conflicts in the airflow in air intakes and exhausts by blocking natural wind flow. Surrounding buildings may also influence the local wind pattern and affect natural ventilation and air infiltration. Exterior-wall exhaust and supply intake grille locations should be properly sited to avoid contamination from outdoor sources and exhaust outlets. Guidelines on air intake positioning are regularly updated in the ASHRAE Fundamentals (1997).

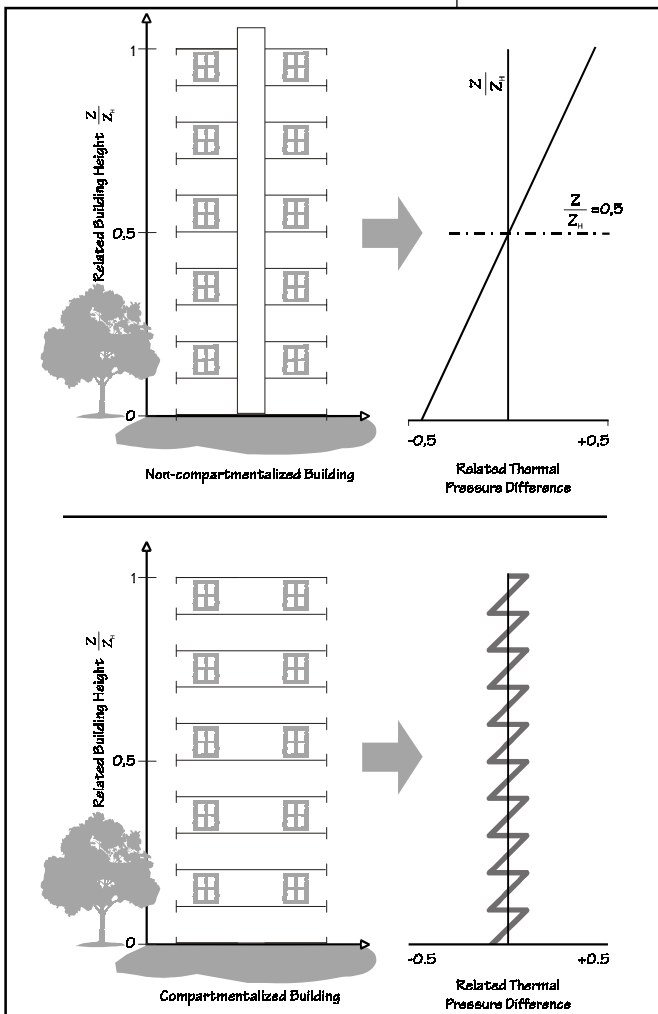
**Figure 5: The “Stack Effect”**



When siting airflow intakes and exhausts, use common sense; for example, do not place an air intake in a loading dock area or next to a building exhaust outlet. For a more detailed explanation of air supply and exhaust placement, see Chapter 6.

- Understand the role of building construction in airtightness and building integrity**—Building airtightness varies considerably depending on the method and quality of construction. Sometimes apparently identical buildings of different construction quality can exhibit completely different performance in terms of ventilation effectiveness and energy consumption. The following descriptions illustrate some of the more common physical consequences of different types of construction and poorly installed ventilation systems.

**Figure 6: Reduction in Stack Pressure Differentials Due to Compartmentalization**



- The “Stack Effect.”** In buildings with large vertical flow paths between floors, such as elevator shafts, cold outside air infiltrates at the lower part of the building and warm indoor air exfiltrates at the upper part of the building during cold weather. (See Figure 5). This phenomenon is known as the “stack effect.” Note that, during colder weather, odors, pollutants, and stale air from lower floors rise to upper floors, and the spreading of smoke and fire, indoor air-quality, comfort, and energy-efficiency are adversely affected. In warm weather the air flows reverse.

**Solution.** By reducing vertical connections between floors (e.g., sealing where vertical plumbing cracks pass through floors and ceilings) it is possible to compartmentalize individual stories and minimize the stack effect. Figure 6 shows that when each story of a building is compartmentalized, the stack effect is reduced from total building height to only floor-to-floor height.

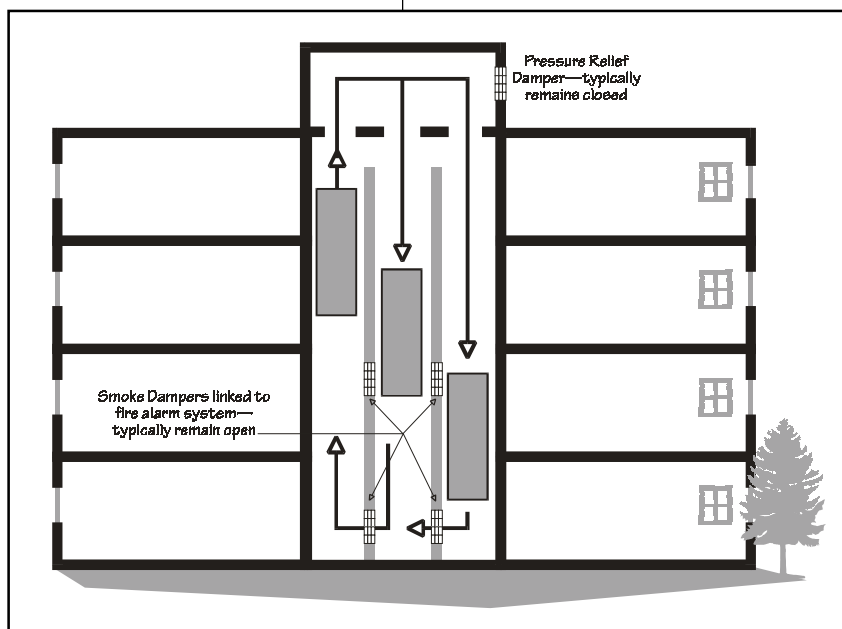
Further information on diagnosing airflow patterns in buildings can be found in Chapter 4. Further discussion of the related thermal pressure difference can be found under the section entitled “Ratios to Describe Airflow Distribution” in Chapter 4.

- **Elevator Shaft Impacts.** Elevator shafts can create significant ventilation and energy impacts. For example, oversized relief vents at the top of some elevator shafts increase the air flow due to stack effect and infiltration. This problem is apt to occur when the elevator penthouse is ventilated by a cooling fan, and the elevators are allowed to run at the same level simultaneously.

**Solution.** Equalizing the pressures between the elevator shafts allows for reduced venting to the outside. By sealing off the pressure relief damper except at the moments when elevators are moving simultaneously up and down at same elevation, the effects of air movement in the shafts can be reduced significantly (See Figure 7). In the improved scenario, the elevator penthouse is conditioned by the heating and cooling system instead of a ventilation fan. Nevertheless, the associated energy savings from this strategy far outweigh the additional cost of heating and cooling the penthouse. Before implementing this strategy ventilation designers should determine whether code requirements will be met in their locality, and if an alternative means for venting between the stacks has already been provided.

- **Unsealed Ductwork.** Ducts are used to distribute mechanically-driven supply and exhaust air throughout a building. If left unsealed, or if poorly sealed, ductwork can cause a variety of problems that include large energy penalties, misdirection of airflow patterns, and unsatisfactory (and often insufficient) delivery of ventilation air.

**Figure 7: Improved Airtightness in Elevator Shafts**



**Solution.** Reducing duct leakage through quality installations, renovations, and sealing leaks will increase delivered airflow, improve ventilation patterns, and save energy and money. Although duct leakage measurement and improved installation and sealing methods have been developed for single-family housing, similar efforts have been lacking in the apartment building sector.

□ **Design ventilation strategies for different building types—**While ventilation needs vary due to the variety of apartment building types, layouts, and construction methods used, securing proper ventilation is important in each of them. When planning a retrofit, ventilation strategies should be adapted to different building types. General ventilation strategies for the common apartment buildings are described below.

- **Low-rise apartment buildings.** Mechanical ventilation systems for low-rise apartment buildings are common in countries with severe climates such as Canada and Scandinavia. In milder U.S. climates, where the need for mechanical ventilation systems is less critical because windows are often used during the winter, the cost of these systems is often prohibitive.
- **High-rise apartment buildings.** In cases where each high-rise apartment unit has a self-contained mechanical ventilation system, care must be taken to ensure that inlets to the apartment (windows, air vents or mechanical air intakes) are not contaminated by exhaust from ventilation outlets or combustion flue gases from adjacent apartments or buildings. Additionally, supply inlets should not be located next to exhaust outlets from a combustion system (e.g., hot-water heater exhaust). To minimize contaminating supply air, centrally-ducted ventilation and heating systems may be necessary, especially in gas- or oil-heated buildings.
- **Masonry (brick) construction.** In this type of construction, air tends to infiltrate through gaps left by missing mortar and other cracks and gaps in the brickwork. Further leakage sources include floor/ceiling-to-wall interfaces, window and door-frame joints, and service penetrations. Floor joists sometimes run across openings in the interior walls, leaving large penetrations into the interstitial spaces of the building. Regardless of these design tendencies, masonry buildings can be constructed to a high degree of air-tightness.

- **Wood-frame construction.** These buildings are typically not airtight because they have the potential for substantial air leakage at building joints.
- **Curtain wall construction.** This type of construction is often very leaky. Gasketing and sealing all joints helps to prevent high infiltration rates.
- **Cellular-type concrete construction.** This construction is often the most airtight of all modern apartment construction types. In these buildings, prefabricated panels containing window and door sections are sealed into the open faces of the concrete structure, resulting in a very airtight structure. It is imperative that a well-designed ventilation system be installed in this type of building to provide sufficient air change rates.





# Chapter 4 – Causes and Diagnostics of Ventilation

## Overview

Design strategies that violate the principles of physics do not make for better-ventilated buildings. In general, airflow is caused by physical differences in pressure in any given area, and does not, as some technical drawings would have one believe, obey schematic directional arrows. A building's construction (type, layout, and materials), natural and mechanical ventilation systems, unintended air flow patterns, wind speed and direction, and the climatically-related indoor/outdoor temperature differences all factor into the appropriateness of any ventilation strategies.

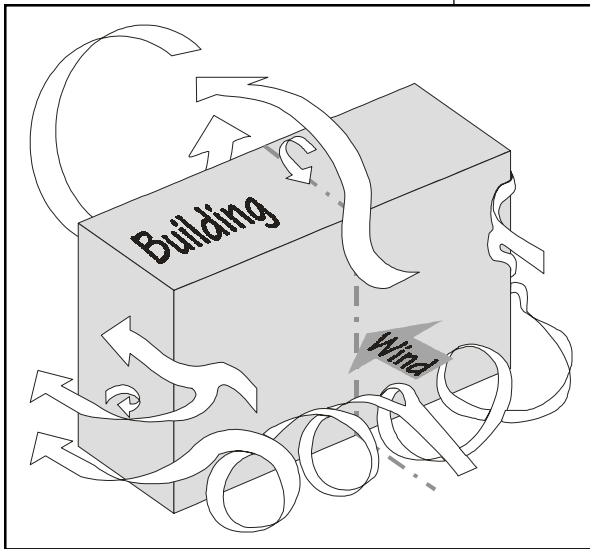
To understand the causes and evaluate ventilation-related diagnostics in apartment buildings, the principles of airflow must be understood. Air flows from areas of high pressure to areas of low pressure. In buildings, pressure differences are caused by wind and temperature differentials, as well as the action of mechanical ventilation systems. The physics of ventilating apartment buildings are inherently complex and will typically require complex diagnostic methods to determine 1) What ventilation strategies are needed or 2) Whether existing systems are operating as designed. While climate-related wind and temperature changes remain outside the ventilation-designer's control, he or she can choose to selectively reduce leakage throughout the building and specify modifications or mechanical ventilation strategies to provide sufficient ventilation.

## Contributors to Airflow

Air movement in a building is caused by pressure differences that occur due to a combination of wind pressure, thermal buoyancy, and mechanical ventilation. Airflow is also influenced by the distribution of openings in the building shell, by inner construction and partitions, and by occupant-use patterns.



**Figure 8: Air Flow Around a Building**



This Section describes the physics of the following factors:

- Wind pressure (velocity and direction)
- Temperature differences
- Airflow patterns and distribution (due to building construction and occupant behavior)

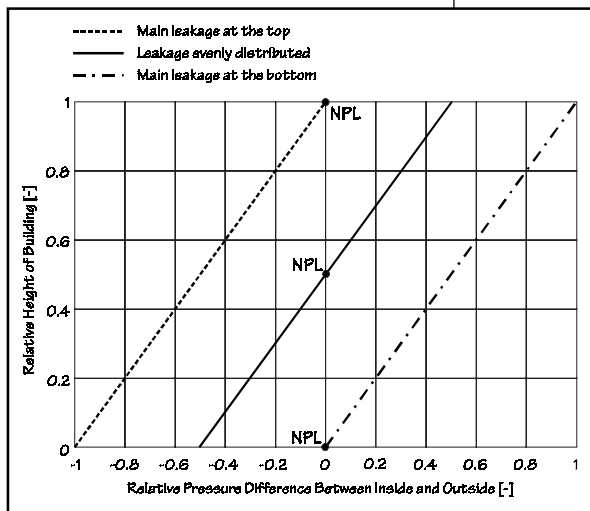
## Wind Pressure

The air flow caused by wind velocity and direction (wind pressure) can have a profound effect on the types of ventilation strategies used in multifamily apartment buildings. Figure 8 depicts the typical wind pattern that can develop when wind strikes a building head on.

## Temperature Differences

Temperature differences between the outside and inside air create air-density differences that cause pressure gradients. The difference in pressure gradients is called “stack effect” or “thermal buoyancy.” The air movement due to stack effect in apartment buildings can easily exceed the air movement caused by wind pressure. The stack-effect pressure gradient depends upon temperature differences between the inside and outside of a space, the vertical dimension of the structure, and its vertical flow resistances. The higher the building and the greater the temperature difference between these two columns of air, the greater the stack-effect. This effect is often misunderstood to be pressure difference within a single column of air (convection). The effect actually deals with the weight differences between the inside and outside columns of air. Buoyancy forces try to even out these differences, causing an overpressure at the top and an underpressure at the bottom of the warmer column of air.

**Figure 9: Stack Pressure Differences as a Function of the Vertical Leakage Distribution**



Another factor affecting stack effect-induced pressure differences is the location of the Neutral Pressure Level (NPL). The location of the NPL is determined based on the distribution and size of leakage sites on the vertical shell of the building. The NPL is defined as the height on the building façade, where, under calm conditions, no pressure difference exists between the inside and the outside. The resultant stack pressures (as a function of vertical leakage) are shown in Figure 9.

## Stack Effect in Hot and Hot/Humid Climates

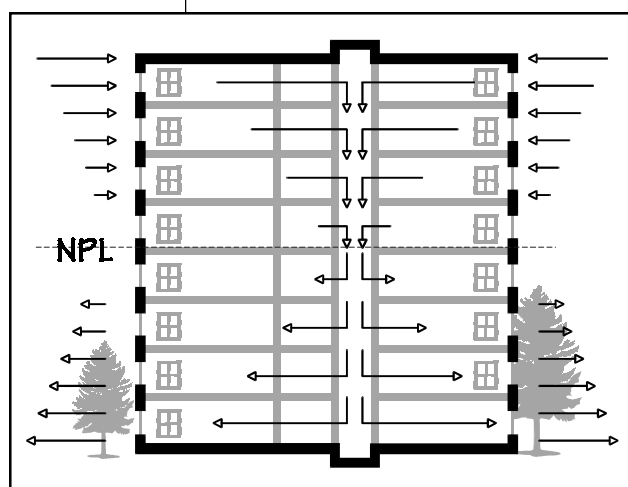
While much of the work in improving ventilation has occurred in cold climates, there are a significant number of apartment buildings in the hot and hot/humid regions of the country. Pioneering work in this area has been done in North Carolina and Texas. Figure 10 shows how the basic principles of stack effect apply in hot climates. In addition to the reversal of flows, the magnitude of the effect is usually less than in cold climates because of the smaller temperature differences between inside and outside.

For example, in a warmer climate where it is common to have an outside temperature of 90 degrees, the HVAC system may cool the building to 72 degrees. This allows for an 18 degree difference between the inside and outside air, as compared to colder weather where a 40 degree difference is common. Because of this smaller temperature/pressure gradient, compartmentalizing the floors of apartment buildings in warmer climates will result in smaller energy saving impacts than compartmentalizing buildings in colder climates.

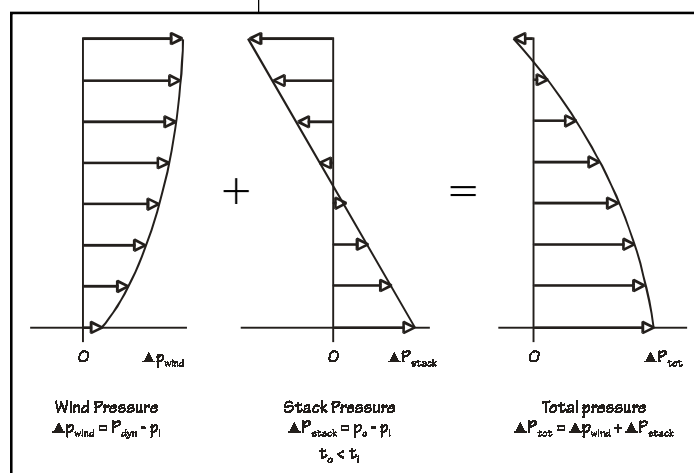
## Superimposition of Flows

To accurately gauge the amount of airflow that occurs from the effects of wind and stack effect, one must superimpose the pressures caused by these mechanisms. Airflows caused by these mechanisms are not additive because the flow rates are not linearly proportional to the pressure differences. To superimpose the flows, the wind and stack pressures must be added as in Figure 11. The length of the arrows represent the amount of pressure differences between inside and outside the building at different heights.

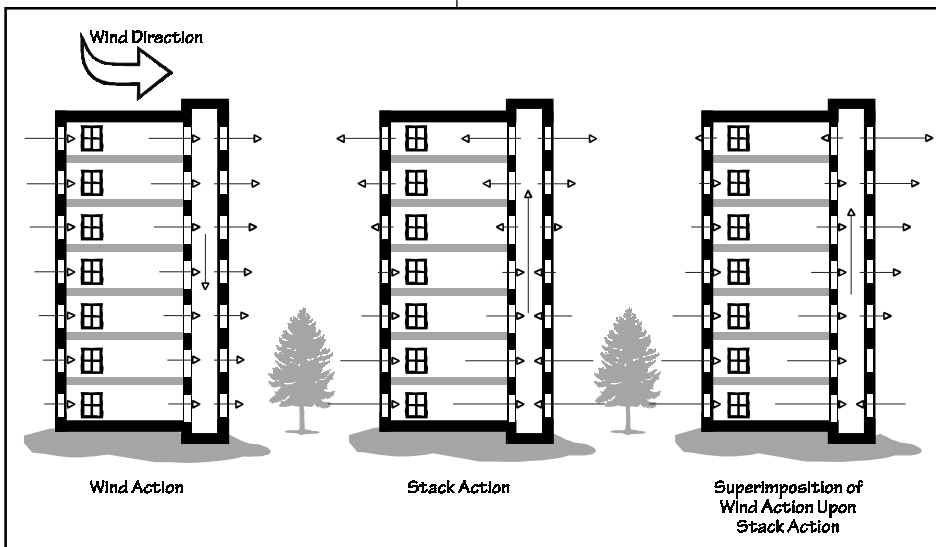
**Figure 10: Stack Effect in Hot and Hot/Humid Climates (Reverse Stack Effect)**



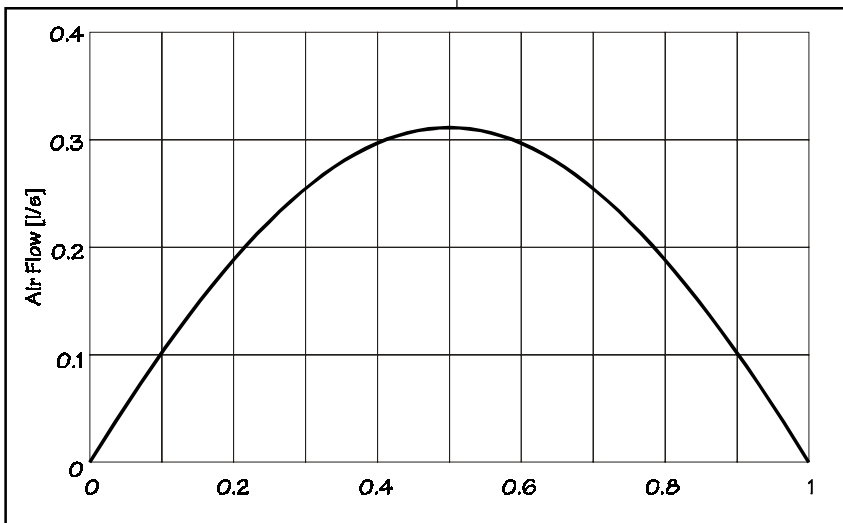
**Figure 11: Superimposition of Wind and Stack Pressures on the Windward Side of a Building**



**Figure 12: Superimposition of Flows Due to Wind and Stack Actions**



**Figure 13: The Envelope Permeability Ratio**



In Figure 12, the NPL is higher on the windward side of the building, and lower on the leeward side. In this case, the stack action causes an upward flow in the elevator shaft while the ventilation causes a downward flow. When these flows are superimposed, the result is a smaller upward airflow in the elevator shaft, greater infiltration at the base of the building on the windward side, and greater

exfiltration at the top of the building on the leeward side. In some instances, when wind forces exceed stack forces, the NPL can be above the building height on the windward side and below ground level on the leeward side.

## Ratios to Describe Airflow Distribution

Building design can dictate how air moves through individual apartments.

Two ratios can be used to describe air

movement through a multi-story building. The first, the envelope permeability ratio—or EPR—is used to describe horizontal airflow through buildings. The second, the vertical permeability ratio—or VPR—is used to describe vertical airflow through buildings.

The EPR describes the distribution of the permeability of the building's envelope. EPR is defined as the ratio of the permeability of the leeward sides to the permeability of the overall building envelope. Permeability can be expressed in terms of leakage area (square feet) or permeability coefficients.

The largest airflow through the building envelope occurs when the EPR is 0.5, which means that the permeability is evenly split between the windward and the leeward side of the building. (See Figure 13).

The Vertical Permeability Ratio (VPR) is the ratio of the floor-to-floor permeability to the overall permeability of the building envelope. The VPR determines the location of the Neutral Pressure Level (NPL). With regard to thermal pressure distribution, two extremes exist, “story-type buildings,” with no permeability between floors ( $VPR = 0$ ), and “shaft-type buildings,” with no airflow resistance between the different stories ( $VPR = 1$ ). The vertical permeability ratio for real buildings is somewhere between these theoretical limits.

## Methods for Estimating Airflows and Energy Impacts

The methods used to determine airflow can be simple or complex depending upon the level of detail that is necessary. For example, if ventilation is perceived as necessary only to remove odors and moisture, then inspection and interviews with residents may determine whether ventilation is sufficient. However, if efforts are underway to tighten the building shell for energy efficiency, air-leakage measurements may be needed to determine how much mechanical ventilation is necessary to meet codes and standards.

Measuring apartment airflows is difficult and requires experience. Unlike the single-family building sector, there are no standard protocols for measuring airflow in apartment buildings. Several practitioners and researchers have developed their own unique methods and protocols to measure airflow in apartment buildings. In the remainder of this Chapter, the following five strategies to determine airflow and ventilation system performance are described.

- Surveys and interviews
- Evaluation by building type
- Diagnostic tools
- Computer simulations and modeling
- Estimation by proxy

## Surveys and Interviews

**Surveys.** An inspection of the building during a walk-through survey can reveal many signs as to whether or not the building has adequate (or excessive) ventilation. Tell-tale signs include noticeable odors, signs of mold or mildew, taped or blocked ventilation grilles, unvented dryers and/or combustion appliances (such as space heaters), and windows left open during cold weather.

In some cases, ventilation may be worse during different times of the year. It may be necessary to perform surveys in the same building at different seasons. Activities, such as drying clothes on indoor clotheslines in winter, may signal a need for additional ventilation.

**Interviews.** Interviews with building owners, residents, and managers can reveal whether ventilation is adequate. Anecdotes or complaints of cooking odors or tobacco smoke from neighbors or hallways can signal problems with too little or too much ventilation.

## Evaluation by Building Type

Similar types of apartment buildings may have similar ventilation characteristics. Of course, there can be variations among individual building types. As will be discussed during the measurement results section, there are very few measurements of air change rates in apartment buildings. However, the data suggest that, for low-rise apartments (frame and brick construction), the range of air changes is 0.5 to 1.5 ACH, while the range of air changes is 0.2 to 1.0 ACH for high-rise concrete structures. Variables that influence these air change rates in different multifamily dwellings are discussed below.

**Low-Rise Row Houses.** These buildings often have no mechanical ventilation except for local kitchen and bath exhausts. There are often major air pathways between adjacent units even though they are technically separated due to fire codes.

**Low-Rise (three-to-five story) Walkups.** These buildings often have no mechanical ventilation. Large central staircases and other vertical connections between floors can create large stack effects. There are often major horizontal airflow paths between apartments. During the heating season, the top units often

have moisture problems in the walls due to the warm exfiltrating air and the bottom units have high energy bills from the cold infiltrating air. Older buildings have bathroom and kitchen vents or operable windows opening onto passive vertical ventilation chases.

**High-Rise Towers.** These buildings typically have mechanical ventilation that may or may not be adequate or operable. Because of their overall height, there is often significant infiltration due to the stack effect. In highrise masonry construction, there are often few horizontal connections between apartments.

## Diagnostic Tools

There are no easy approaches to measuring the ventilation in an apartment building. To obtain useful results, it is necessary to measure airflow from mechanical systems (if any are present) and measure airflows due to infiltration and exfiltration. Diagnostic test equipment, such as blower doors, digital manometers, and tracer gases (described below) can record preliminary measurements. These preliminary measurements are used to help ventilation specialists develop an understanding of the pressure boundaries in the building. Repeated measurements should be taken to verify or refute initial readings.

Mechanical ventilation airflow can be measured using flow hoods (balometers) which measure the pressure difference across the flow hood fan, or by using other flow-measuring devices, such as duct blasters. Measurements are gained by positioning these devices at the individual supply and exhaust registers throughout the building. Most flow hoods cannot accurately measure flows below 25 cfm. Energy practitioners have developed creative solutions using “calibrated” buckets and garbage bags to estimate flows from registers in apartments. One simple device is a cardboard box with a hole cut in the side. A credit card taped over the hole will stand out about an inch if the airflow out of the hole is greater than 20 cfm.<sup>1</sup> The standard research approach for measuring infiltration is to use tracer gases to measure airflow and air exchange in an apartment. Various techniques are available, from miniature passive samplers to larger real-time monitors. Tracer-gas measurements give a “snap-shot” of infiltration, and are useful to measure leaks through the building envelope and fan flow rates—showing the infiltration and airflow rates that occur during the test, at particular weather and building conditions.

<sup>1</sup> Brennan, 1996.

Blower doors are used to measure infiltration or exfiltration. When using a blower door, all known air entryways are blocked off. A high pressure fan is then placed inside a doorway, and either pressurizes or depressurizes the building structure (depending on whether the fan directs air into or out of the building). On average, pressure will be increased to 50 Pascals (+/-). Multiple blower doors can be used to determine airflow between apartments, as well as airflow from outside the building. Building envelope leakage locations can be pinpointed by noting where tracer gases or smoke exit or enter the pressurized or depressurized building. Another way to pinpoint leakage locations is to use an infrared camera to observe changes in heat patterns caused by infiltration and exfiltration through the building shell.

## Computer Simulations and Modeling

Simulation and modeling efforts can be used to understand the general airflow principles in prototypical buildings. A computer simulation can “model” all the various airflow patterns in a building under different outdoor temperature and wind conditions. Such models simulate the flow through leakage areas and integrate other physical characteristics of the building that cannot otherwise be measured.

## Estimation by Proxy

In cases where the building has individual utility metering data for each apartment, it is possible to see patterns of infiltration and ventilation by looking at electricity used for space heating and cooling in the individual apartments.

## Field Measurements of Infiltration and Ventilation in Apartment Buildings

There is a limited amount of published data available on measured ventilation rates in apartment buildings. Apartment building airflow measurement work can be difficult due to the complexities of the building. Much of the uncertainty surrounding ventilation codes and standards could be eliminated if accurate methods of quantifying airflow in apartment buildings were readily available. Following is a brief description of related research findings. The citations for these studies can be found in the References section of this Guidebook.



Using a variety of techniques (tracer gas, single or multiple blower doors, blower doors with digital manometers, etc.), apartment air change rates ranging from zero to several air change rates were seen—often within the same building. Researchers have been able to establish that, in many cases, 30% to 60% of the air leaving an apartment may leak into adjacent apartments, resulting in “re-cycled” airflow. Researchers have compared actual inter-zonal airflow data with a computer simulation, finding that uncertainties due to wind fluctuations were no greater than 10% for wind speeds of less than 5 m/s (~ 11 mph). Airflow measurements of a project that involved installing “sheet-rocked boxes” inside the building’s original brick walls (thereby effectively compartmentalizing the building) found that the individual apartments and hallways were quite airtight. In studies that measured ventilation system airflow rates, researchers often found rates to be much less than the designed airflow rates. These findings show that both in theory and in practice, focusing airtightening efforts on sealing air bypasses between apartments, especially in colder climates, as well as concentrating on improving or installing ventilation systems, can help to improve a building’s ventilation effectiveness.



# Chapter 5: Designing a Ventilation Retrofit

## Overview

This Chapter contains recommendations for improving ventilation in different types of apartment buildings (high-rise and low-rise), and also recommends tips for optimizing natural and mechanical ventilation strategies.

There are several strategies that can be used to improve ventilation in apartment buildings. Choosing any particular strategy or set of strategies should depend, at minimum, on an analysis of how climate, building configuration, previously installed ventilation equipment, operation and maintenance practices, system first costs, and potential energy savings will affect their success. In most cases, reviewing the energy bills and architectural drawings will help determine specific retrofit design options.

Acceptability by occupants, ease of use, reliability, and noise performance are also important considerations. Ventilation codes and standards recommend or require a minimum amount of outside ventilation air and can be used to guide the design and operation of a ventilation system.

## Ventilation-Related Issues to Remember

Some important issues to think about when designing a ventilation strategy include the following:

- Local climate
- Local energy prices
- Building airtightness, interstitial spaces, and vertical and horizontal connections
- Pressure balances between zones
- Ventilation system distribution and coverage



- Ventilation strategies for different building types
- Occupant needs
- Health and safety issues
- Maintenance and operation issues
- Combustion-appliance safety issues

## General Design Suggestions

The suggestions below include a discussion of ventilation design, building air-tightening, compartmentalization, and pressure imbalances. These suggestions apply to both high- and low-rise apartment buildings. “Air-tightening” is sealing unintentional leaks within the building, or in the “building envelope”—that is, in the building’s outer shell, walls, and roof.

Good ventilation design is essential to ensure the reliable provision of outside air to building occupants. When designing a strategy, think it through well in advance. Care should be taken not to use a “blanket” approach to ventilation, since there is rarely a simple solution to a building’s ventilation problems. In specifying a ventilation strategy, it is important to review the constraints imposed by building type, climate and location, the level of airtightness to be accomplished, as well as cost performance, energy performance, reliability and ease of maintenance.

In particular, ventilation design should satisfy the following basic requirements:

- Do no harm
- Provide all residents with outside air
- Comply with relevant building regulations and associated standards and codes
- Satisfy minimum recommended ventilation rates for optimum health and comfort
- Be capable of removing pollutants at the source before they disperse into occupied areas
- Be compatible with the building in which the system is installed
- Incorporate occupant or automatic controls to ensure that the ventilation rate can be adjusted to meet changing demands

- Be reliable
- Be user-friendly
- Be capable of being cleaned and maintained
- Comply with smoke and fire control requirements
- Be cost-effective and energy efficient
- Improve building's airtightness

## Building Air-tightening and Compartmentalization

Energy-efficient ventilation performance can be destroyed if the airtightness of the envelope and the internal partitions are not compatible with the ventilation strategy or climate. In both moderate and severe climates, airtightness requirements and compartmentalization are significant concerns for many building types. Mechanical ventilation systems are most efficient when good internal separation (building compartmentalization) between units and floors exist, and when the building envelope is airtight. Building compartmentalization is an integral part of envelope air-tightening, and is essential when tightening building envelopes in colder climates.

### Essentials of Envelope Tightening

- Determine sources of poor airtightness performance
- Use professional construction techniques
- Be aware of standards for envelope air-tightening
- Look for durability and airtightness performance standards for windows, doors, sealants and sealing components

## Essentials of Building Compartmentalization

- Compartmentalize buildings over three stories in colder climates
- Weatherstrip corridor doors for airtightness
- Seal off vertical shafts (utility chases, garbage chutes, mail drops) at each floor
- Separate elevators from corridors by installing vestibule doors

The building's ductwork must be airtight as well. Airtightening practices are needed to reduce the leaks present in the building's ductwork. Duct leakage can occur as a result of poorly installed and maintained duct connections, or in extreme cases, physical damage to the ductwork itself. Some duct systems have cloth duct tape "sealing" the joints between ducts. The cloth tape does not last as long as the preferred mastic or metal-backed tape at duct junctions. Ductwork leakage can be a source of considerable energy waste, especially if the leakage occurs in spaces that do not need conditioning (such as crawlspaces, service shafts, etc.). Not only will the fan have to deliver more air, but more air must also be conditioned to compensate for the leak. Other problems may also result from duct leakages. For example, warm moist air leaking from the ductwork of an exhaust system may result in damage to the exterior envelope in unheated spaces.

## Pressure Imbalances

Pressure imbalances can be caused by climate, building construction, interior airflow patterns, and mechanical systems such as ventilation fans and forced air heating and cooling systems. It is important to take these factors into account when evaluating and developing apartment ventilation solutions. Pressure imbalances can cause backdrafting or spillage of combustion appliances (i.e., naturally-vented furnaces, water heaters, fireplaces, woodstoves, and unvented space heaters). Backdrafting and spillage occurs when there is a negative pressure in the area of the combustion appliance that causes combustion products to be drawn back down the flue and spill out into the building space. This condition can create life-threatening risks.

## Warding-off Pressure Imbalances

- Determine what types of combustion appliances are in the apartments and the building
- Isolate naturally-vented combustion appliances, such as gas furnaces, water heaters and boilers, in a separate room or area outside of the living space
- Install sealed-combustion appliances (gas furnaces, water heaters and boilers) if it is not possible to isolate them outside of the living space (Note that sealed-combustion appliances are preferred wherever possible)
- Use weatherstripping and gaskets on doors that separate naturally-vented combustion appliances from the rest of the apartment or living space
- Provide combustion make-up air (via vents or ducts) from outside of the building directly to the combustion appliances or to the space in which they are located
- Do not locate clothes dryers and other exhaust fans in the same room as naturally-vented combustion appliances
- Provide combustion make-up air directly to fireplace and woodstove fireboxes
- Avoid installing unvented space heaters as they vent combustion products directly into the space and can create life-safety risks

## The Cost of Mechanical Ventilation

Often ventilation designs must effectively balance sound ventilation strategies while minimizing ventilation-related energy costs. However, rather than thinking of ventilation-related costs as an “extra” cost, they should be seen as a necessary cost. Ventilation installation and operating costs can be optimized by looking at energy-efficiency options. These may include efficient fans, optimally-sized systems, energy-recovery ventilation, and air-tightening and compartmentalization. The following costs should be considered when deciding upon a ventilation system:

- Initial system costs
- System fan and motor operation and maintenance costs
- Thermal conditioning costs
- Energy and cost performance

## Initial System Costs

The cost of the ventilation system will depend on the choice of equipment and the ease of installation. Depending on the technology, residential-type ventilation systems—such as those typically installed in single-family houses or individual apartments—have combined equipment and installation costs ranging from \$500 to \$1800<sup>1</sup>. Simpler systems, such as exhaust only, cost \$500 to \$600. Distributed supply or exhaust systems can be in the \$700-\$1000 range and energy-recovery ventilation and supply-dehumidification systems cost \$1500 to \$1800. Equipment cost information databases can be used to estimate costs for larger ventilation systems, such as a whole-building, multi-unit ventilation system. Important installation cost factors to consider include building construction, existing ventilation systems, and whether other renovation work is being done.

Often servicing an already existing ventilation system instead of purchasing and installing a new one will save time and money. In buildings that lack any mechanical ventilation, mechanical retrofit options are more costly. In cases where ventilation systems are not already in place, new exhaust fans are installed and air inlets placed where needed. An expanded discussion of ventilation options is provided in the following chapter.

## System Operation and Maintenance Costs

The cost of operating a ventilation system includes the cost of electricity to run the fan motors, system maintenance costs, and equipment replacement costs. The cost of fan motor operation depends on the characteristics of the fans and motors. Operating costs can be calculated using the local energy rates and fan energy consumption rates. Typically, central supply fans (500-5000 cfm) are powered by one-quarter to one horsepower motors, while exhaust fans (50-500 cfm) are much smaller. Energy-efficient motors, and optimally-sized ductwork systems can help reduce the overall energy costs. Maintenance for the central supply fan systems involves two-to-four hours of labor every six months.

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<sup>1</sup> Roberson and Matson, 1997.



## Thermal Conditioning Costs

Basically, the cost of conditioning ventilation air depends on the climate and the temperature preferences of the occupants. Humidification and dehumidification are also important factors in the cost equation. In many locations, ventilation air needs to be heated in winter and cooled in summer. The most common heat sources are gas and electricity. Gas heater efficiencies are typically above 80 percent. A Canadian study of four high-rise residential buildings estimated the costs associated with ventilation and air leakage to be 13% and 17% of the annual energy consumption, respectively. Energy recovery systems, when cost effective, can reduce conditioning costs.

The cost of conditioning infiltration/ventilation air will vary from apartment to apartment, depending on building conditions, apartment location, etc. When looking at the amount of heating energy used in high-rise apartments, the amount of energy is lower for apartments at higher floors. The drop in energy use has been correlated to reduced infiltration in winter in the upper floors due to the stack effect. The exception to this rule is that the top floor uses more energy because heat is lost through the roof.

## Energy and Cost Performance

A ventilation system must be cost competitive in order for it to be readily accepted by building owners. Ventilation alternatives should be evaluated using payback or life-cycle cost analyses, but care should be taken to include costs that are specific to a particular building, climate, and local energy rates. For example, despite high capital costs, energy-recovery equipment is attractive in areas where the outdoor climate is severe or in cases when the payback period is extended. When using life-cycle costing, alternatives with lower operating costs and shorter payback periods are preferable. In general, an expensive system with lower operating costs will prove, over time, to be more cost effective than a less expensive system that costs a lot to operate and works well for only a short time.

## Performance Analysis

A system performance analysis takes into account all major building ventilation strategies, and quantifies the energy benefits and costs associated with each.

With mechanical systems, the air distribution and air conditioning costs should be identified. Optimum design of mechanical ventilation systems includes:

- Careful fan selection
- Good design and installation of ductwork, and
- Careful use of conditioned air

With natural systems, the heating or cooling losses associated with poor control and risk of over supply should be included in any analysis. Natural ventilation strategies should be judged on the following merits: 1) Their ability to minimize the loss of conditioned air, and 2) Their ability to assist the mechanical ventilation system in using the least amount of energy possible.

## Life-Cycle Planning

Life-cycle planning is an important tool to use when deciding upon a ventilation strategy. Careful life-cycle costing helps designers counter the tendency to choose the ventilation strategy with the least expensive initial capital cost. When designers focus on only satisfying initial system needs, their analysis may not consider the following issues:

- Long-term interactions between building components
- Long-term operational costs
- System reliability, and
- Operations and maintenance costs

By considering the above issues, the quality and performance of each design strategy is integrated into the designer's thought process. Life-cycle planning considers each ventilation strategy from the inception phase through installation and operation, maintenance, and eventual dismantling and replacement.

Suggested strategies in lowering the cost of ventilation include:

- Switching from electricity to a less expensive fuel, such as natural gas or solar pre-heat
- Improving the efficiency of the motors
- Reducing the amount of ventilation air supplied (lowered cfm)
- Reducing the number of hours the ventilation air is supplied through timers and controls during cold periods
- Reducing the infiltration due to wind and stack effect rates through air-tightening and compartmentilization
- Adding an energy-recovery system between the exhaust and supply air streams<sup>2</sup>

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<sup>2</sup> The last strategy suggested, heat recovery, may be cost-effective in very cold climates if the thermal energy and cost savings are greater, on a life-cycle cost basis, than the combined incremental installation costs over a non-heat recovery system, fan operating costs and maintenance costs.

## Calculating Energy Costs

There is a direct correlation between higher ventilation rates and higher fuel bills, although the cost of conditioning air varies from apartment to apartment, depending on building conditions, apartment location, etc. A rudimentary method of estimating the annual energy used for heating ventilation is given by the following formula:

$$Q = VHC * AIRFLOW * HDD * 1440$$

$$(Btu/yr = Btu/ft^3 \cdot ^\circ F * ft^3/min * ^\circ F \text{ day/yr} * \text{min/day})$$

where:

Q	=	the annual energy used to heat ventilation air [Btu/yr]
VHC	=	the volumetric heat capacity of air [0.018 Btu/ft <sup>3</sup> F]
AIRFLOW	=	ventilation air flow [ft <sup>3</sup> per minute]
HDD	=	the annual heating degree days for the location
1440	=	conversion factor [min/day]

This formula assumes that indoor temperatures and the volumetric heat capacity of the air is uniform throughout the building.

As an example, a thirteen story apartment building (approximately 100,000 square feet of living space) has a central fan providing 5000 cfm in a Boston climate of 5600 heating degree days. This assumes that the fan provides 0.35 ACH to the building. The energy needed to heat this air is:

$$Q = 0.018 \text{ Btu/ft}^3 \text{ F} * 5000 \text{ cfm} * 5600 \text{ HDD} * 1440 \text{ min/day}$$

$$Q = 725,760,000 \text{ Btu/yr}$$

If the ventilation air is heated with electricity at \$0.10 per kWh, the annual costs would be:

$$\text{Annual Cost} = 725,760,000 \text{ Btu/yr} / 3414 \text{ kWh/Btu} * .10 \text{ \$/kWh}$$

$$\text{Annual Cost} = \$21,258 \text{ per year}$$





# Chapter 6: Choosing a Ventilation Strategy

## Overview

This Chapter provides recommendations for ventilation strategies for both high-rise and low-rise structures, and describes the exhaust-only, supply-only, and balanced ventilation components used in mechanical and natural ventilation. When choosing a particular strategy, one must keep in mind that it must fit into certain cost parameters. Any compromises in system design should be carefully weighed against a variety of factors before actually implementing the strategy.

## Different Ventilation Strategies for Different Building Types

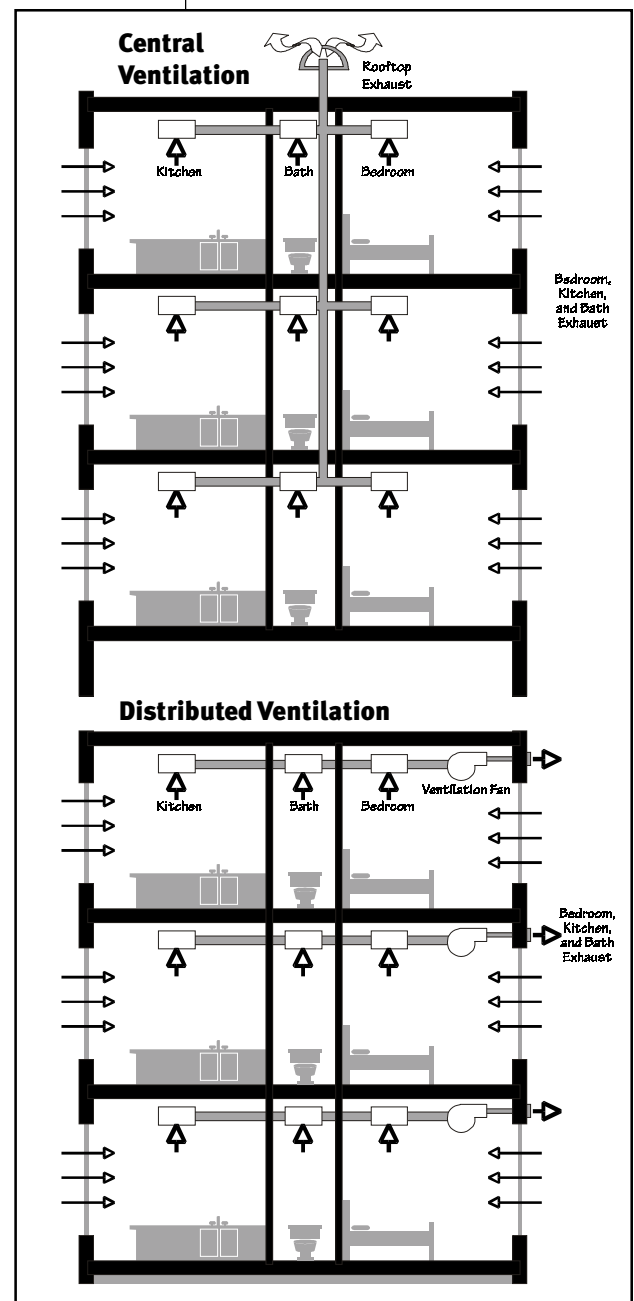
In general, two types of mechanical ventilation can be found in multifamily apartment buildings. These include central systems and distributed systems. Central systems can provide ventilation to multiple units or to the entire building, while a distributed system is made up of individual ventilation systems for each apartment. Central systems, typically found in high-rise apartments, minimize installation and operation costs and may supply and/or exhaust air. Distributed systems are generally found in low-rise apartments, and may supply and/or exhaust air.

Distributed systems include those “stand-alone” fans and motors (such as range hoods or exhaust fans) that work on individually ducted systems. Central systems include larger fans and interrelated ductwork systems that exhaust air from each of the apartments in the building. These two systems are depicted in Figure 14. Grilles and registers provide locations for the air to enter or exit the duct system.

Distributed natural ventilation may include strategically placed windows and inlets. Central natural systems include central ventilation shafts that are usually found in older buildings.



**Figure 14: Central Ventilation vs. Distributed Ventilation**



## Low-Rise Apartment Buildings

Low-rise apartment buildings may include row houses and three-to-five story walkup apartments. Typically, these buildings are less likely to have central mechanical ventilation systems than high-rise apartment buildings. Due to the stack effect and exfiltrating air, low-rise apartments can have high-infiltration rates in lower units and significant moisture problems in the walls of the upper units. In row houses, air movement between adjacent housing units is common, due to unintentional openings between the buildings in the walls, attics, and or basements. These openings violate fire codes, and need to be sealed before infiltration and ventilation issues can be brought under control.

In Montreal, the attics of several three-story brick buildings were retrofitted with high-density cellulose insulation. This action resulted in a 50% reduction in the total building leakage area. Since the buildings proved difficult to compartmentalize, the retrofit entailed installing 70 cfm exhaust fans in the top floor units to remove moisture from the building. This retrofit successfully employed two measures that significantly decreased costs from mechanical ventilation equipment.

### Low-Rise Apartment Retrofit Recommendations

- Seal internal connections between apartments
- Investigate the potential for central and/or distributed exhaust systems, with exhaust air grilles in the kitchens and bathrooms
- Seal leaks between apartments and attics
- If the exterior envelope is too tight and exhaust-only systems are installed, introduce openings for outside air—behind radiators or above windows to minimize comfort issues
- Verify that exhaust fans and systems perform as designed—field experience has shown that a large percentage are not installed correctly
- Locate and eliminate duct leakage



## High-Rise Apartment Buildings

As mentioned previously, high-rise apartment buildings often have central mechanical ventilation systems and bathroom and or kitchen exhaust fans. Often these systems do not operate as designed, and sometimes not at all. Although compartmentalization may be difficult, it is important to isolate vertical shafts and chases as much as possible to reduce stack effect. Consideration should be given to implementing the following recommendations (See box).

### High-Rise Apartment Building Retrofit Recommendations

- Minimize supply air to corridors
- Weatherstrip apartment entryway doors (unless supply air is intended to move under doors)
- Install continuous bath or kitchen exhaust systems with constant air regulators
- Introduce supply-air locations in very airtight apartments
- Locate supply air behind radiators, and direct the airflow upwards
- Seal the top of elevator shafts where allowed by code
- Under-cut bedroom and bathroom doors to allow air movement between rooms
- Use blower doors to identify air leakage paths between apartments
- Seal leaky ducts and building envelopes
- Isolate apartments from garbage chutes, stairwells, elevators, and parking garages
- To minimize retrofit costs, compartmentalize tall high-rise buildings at every third floor rather than at each floor

## System Components Natural and Mechanical Ventilation

The following sections discuss the components of mechanical and natural ventilation systems.

## Natural Ventilation Components

By careful design, it is possible for natural ventilation to provide a satisfactory environment even for a very complex building design. Ventilation requirements can be very demanding, and improved reliability and control are in increasing demand. Natural ventilation components, discussed below, include operable windows and louvers, air vents and “trickle ventilators” and automatic (variable area) inlets.

Natural ventilation relies on the flow of air through openings in the building shell to provide both supply and exhaust air. A well-designed natural ventilation strategy should combine permanently open vents to provide background ventilation, and controllable openings to meet transient demand. The number and size of openings will depend on the overall ventilation needed and the strength of local driving forces (such as wind and stack effect). Sometimes automatic controls and dampers are used to adjust ventilation openings. These may be connected to thermal sensors to maximize potential night cooling.<sup>1</sup>

### Operable Windows and Louvers

In many buildings, operable windows are the principal agents of natural ventilation. They permit the passage of large amounts of air for summer cooling and for a general flushing of the building. Unfortunately, if window opening and closing is not well coordinated with the outdoor weather conditions, extreme discomfort and energy waste can occur during the heating season. Sometimes energy losses are exacerbated if heating systems are over-sized and have inadequate controls, since window opening is then used to moderate indoor air temperature.

### Trickle Ventilators (or “Outside Air Inlets”)

Unnecessary air change can be avoided by using “trickle” ventilators (small air vents) in place of window openings for winter ventilation. They typically have an effective opening area between 6 and 12 in<sup>2</sup> (4000 to 8000 mm<sup>2</sup>). It is best to use non-adjustable trickle ventilators. If trickle ventilators are adjustable, permanently set them to provide the minimum amount of ventilation. Occupants can then open them further if additional ventilation is needed. When used by themselves, trickle ventilators provide limited but “uncontrolled” ventilation. At least one vent per room is normally recommended for naturally ventilated dwellings.

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<sup>1</sup> Martin, 1995

Trickle ventilators should be positioned to promote the entry and rapid mixing of outdoor air. This is necessary to ensure good air distribution and to prevent uneven localized areas of cooling. To prevent discomfort, it is often recommended that vents be located at a high level, (i.e., above the window and possibly integrated into the window frame). Sometimes ventilators are positioned directly behind wall-mounted heaters or radiators. This arrangement prevents unauthorized access to the vents and enables the incoming air to be pre-heated before reaching the occupied zone and it also prevents unauthorized access.

## **Automatic (Variable Area) Inlets**

Some air inlets respond automatically to such parameters as the outdoor temperature, humidity ratio, or air pressure. These parameters are usually the basis in designing a passive stack (or natural exhaust) ventilation systems.

### **Temperature-sensitive Vents**

The size of the temperature-sensitive vent opening reduces as the outside air temperature falls. This feature limits the amount of unintended air flow due to the stack effect.

### **Humidity-sensitive Vents**

The humidity-sensitive vent opens in response to increased room humidity to assist in moisture removal. These vents are popular in some cold climates.

### **Pressure-sensitive Vents**

Various pressure-sensitive vents have been developed, but they usually do not operate reliably at the normal driving pressures of natural ventilation (i.e., less than 10 Pascals). These vents allow an almost uniform airflow rate to be achieved over a wide pressure range, thus enabling good control of natural ventilation.

## **Mechanical Ventilation Components**

An integrated ventilation design philosophy must ensure optimum performance while achieving maximum energy efficiency. Mechanical ventilation systems are capable of providing continuous controlled ventilation to a space through the use of fans, ducts, diffusers, supply air intakes, supply air inlets, and exhaust air grilles. Some systems also incorporate energy-recovery techniques to reduce

ventilation-related space-conditioning costs. The benefits of mechanical systems must be weighed against the capital and operational costs, on-going maintenance needs, and replacement costs and must be designed to meet the specific needs of the building in which it will operate.

When well-designed ventilation systems are installed in well-constructed buildings, climate parameters do little to degrade their performance. A well-designed building will have a well-sealed building envelope, and increased compartmentalization by blocking and sealing any unnecessary air pathways between apartments. In large apartment buildings, central heating, cooling, and filtration systems can be modified to provide outside air ventilation. The components of mechanical systems are described below.

## Controls

Ventilation systems can include both active and passive flow controllers or dampers to control ventilation based on humidity, temperature, and occupancy. Sensors can be used to detect for carbon monoxide, moisture, smoke, and other pollutants.

## Fans

Fan power is expressed in horsepower and is approximately proportional to the third power of the air velocity. This means that reducing the velocity of air through a duct by half will result in an eight-fold decrease in fan power and fan operating costs. Ducts with large cross-sectional areas can help reduce airflow velocities, but installing larger ducts should be assessed in the context of the additional capital costs and space needs. Fans can be used to propel both the supply air and the exhaust air. Fan energy can represent a significant fraction of the energy budget of a building. Fan energy consumption is dependent on the air flowrate, the pressure drop across the fan, and the fan and motor efficiency.

Propeller fans are commonly used for low airflows. Centrifugal fans are used for higher airflows and lengthy duct runs. Axial fans and the air foil category of centrifugal fans have a higher energy efficiency. Other categories of centrifugal fans (e.g., forward curved or radial fans which are often used in bathroom exhaust applications) have a lower energy efficiency and should be avoided.

Noise criteria should be taken into account when selecting a fan. If selecting a large motor or fan, select a “premium efficiency” or “EPAct-rated” fan. Some control strategies for maximizing fan efficiency include:

- For single phase motors, sub-fractional motors (less than 1/2 hp, bathroom-type exhaust fans), use permanent split capacitor (PSC) motors
- For single phase, fractional motors (1/2 to 1 hp) motors, use capacitor start/capacitor run motors
- Use Motormaster, a motor selection tool from the Department of Energy’s Motor Challenge Information Clearinghouse, to select an energy-efficient fan motor
- In examining existing and new fan motors, check that the motor is not overloaded and re-amp a new motor after installation to make sure that it is sized properly.

## Ducts

Ducts are used to transport the ventilation air in, out, and throughout the building. In order to minimize operating costs, duct airflow resistance should be minimized. The airflow resistance in the duct is affected by the following:

- The airflow rate through the duct
- The duct cross sectional area
- The length of the duct run
- The number and angles of duct bends
- The relative roughness of the duct inside surface

As duct resistance increases, more electrical energy is needed to drive the system fan motor. Greater flow resistance increases the ventilation system noise. Minimizing the resistance to air movement can reduce fan energy. Well-designed duct systems require electrical power of 0.5 Watt or less for each cfm of airflow. Poorly designed systems may need 2 Watts per cfm or more to deliver the same airflow rate. Low-loss fittings and repositioning filters and cooling coils can minimize airflow resistance. Ducts that pass through unconditioned spaces should be insulated and well-sealed to prevent thermal losses, condensation, and leakage.

## Registers and Grilles

Registers and grilles are used to discharge mechanically supplied air into ventilated space or to draw exhaust air out of the space. Design specifications for registers and grilles must consider the flow rate, discharge velocity, and turbulent intensity.

## Outside Air Intakes

Outside air intakes are openings where outside supply air is collected and ducted to a mechanical ventilation system. Indoor air quality problems occur if these outside air intakes are located close to the the contaminant sources (e.g., traffic fumes or local industry or building exhausts).

## Outside Air Inlets

Outside air inlets are passive openings that are used to supply outside air to the conditioned space. They may consist of trickle ventilators or other openings used for natural ventilation. These intentional openings are located in exterior walls or integrated into exterior window frames, and allow a small amount of outside air to enter the space. (See page 56 & 57 for more details on outside air inlets.)

## Noise Attenuators

The noise in mechanical ventilation systems can cause considerable occupant discomfort. Direct noise includes noise from fans, sharp bends in ducts, undersized ducts, poor mountings, control valves, and aerodynamic noise (through grilles). Noise from outside may be transmitted into a building through the ventilation ducts. While it is best to design and install a duct system without these problems, additional strategies may be warranted. The most common strategies include the sound-proofing ducts with sound absorbing material and using “silencers” or noise attenuators. These consist of a perforated inner duct surrounded by mineral wool packing which is enclosed by an outer duct. Both techniques increase the flow resistance and, therefore, incur an energy performance penalty. Installation costs are also high. Through proper system design, designers may prevent the need for these measures.

# Strategies for Mechanical and Natural Ventilation

A wide range of systems and techniques are available to meet the needs of ventilation, with each having the potential to meet specific applications. Ventilation strategy choice is often dictated by the local climate conditions or building type. Frequently, price competitiveness and a reluctance to deviate from the minimum specifications of relevant building regulations or codes can further restrict choice and also limit the opportunity for innovation. To justify a complex strategy, it is usually necessary to demonstrate advantages in terms of improved indoor climate, reduced energy demand, and acceptable payback periods. Choice ultimately is dependent on such factors as indoor air quality requirements, heating and cooling loads, outdoor climate, cost, and design preference. Above all, the selected system must satisfy the design criteria. This section describes mechanical and natural exhaust, supply, and balanced ventilation systems.

## Mechanical Ventilation Strategies

As discussed previously, mechanical systems can supply and or exhaust air. In general, mechanical exhaust ventilation systems use fans to remove air from a space by inducing suction or “under-pressure” which causes the flow of an equal mass of supply air into the space through intentionally-provided air inlets or infiltration openings. If the under-pressure created by the fan is greater than the pressure from wind and temperature gradients, then the fan will continue to exhaust air properly. Optimum operational efficiency is achieved when mechanical pressure is slightly greater than the weather-induced pressure. The best exhaust control occurs when internal separations are airtight and intentionally-provided air inlets/intakes are supplying the air (and not exhausting it).

Mechanical supply ventilation strategies introduce air into the building to mix with existing air. Ventilation supply air may need to be conditioned in order to ensure occupant comfort. Occupants who live in cities, or are sensitive to pollutants and allergens (e.g., pollen, industrial emissions, etc.), may benefit from the use of filtered supply air. If the supply system is well-designed and the building has a tight shell, a positive pressure builds within the ventilated space as air is introduced into the building. In this way, supply ventilation blocks the ingress of infiltrating air and insures that almost all of the air entering a space can be filtered (to reduce dust and particulate concentrations) and or thermally

conditioned. Air is recirculated for thermal comfort and blended with the incoming outside air. Optimal performance of a supply system is maintained by sizing the system to operate just beyond the pressure range developed by wind and temperature.

## Mechanical Exhaust Ventilation Strategies (Exhaust-Only Systems)

An exhaust-only system removes air from the apartments while the supply air enters directly from outside. All too often, however, depending on the location of the air leakage sites, the supply air may enter from the corridor, or from surrounding apartments. Generally, there are two types of exhaust-only systems — individual and centralized. Common examples of individual exhaust-only systems are bathroom and kitchen exhaust fans. Centralized exhaust systems, on the other hand, can consist of exhaust fans that are located on the roof or in the basement, and are connected by ductwork to each apartment. Exhaust-only systems work best when the airflow between each apartment and the adjacent spaces is minimized. However, in humid climates, exhaust-only systems may bring unwanted moisture through the building envelope.

Individual exhaust systems are common in smaller buildings where they are used to exhaust pollutants and moisture from the source of production. These are typically low-capacity wall, window, and range-hood fans that vent the contaminated air directly to the out-of-doors. Typical capacities are 50-100 cfm with range hoods typically starting at 100 cfm. Individual exhaust fans are frequently used to support natural ventilation. Operation is normally intended to be intermittent and may include a time switch or humidity sensor for automatic control. Residents can control individual exhaust-only systems by using a dedicated switch, or, as often found in bathrooms, by using a single switch to control both the fan and the main bathroom light. The advantage of resident-controlled switches is that the system is operated only when the occupant chooses, and therefore uses minimal amounts of energy. An obvious disadvantage is that the resident may not be aware when ventilation is needed. A clock timer with removable pegs can be used to program the daily operation of an exhaust ventilation system. Humidity sensors, occupancy sensors, carbon dioxide sensors, or other pollutant sensors could also control exhaust systems.



Centralized ducted exhaust systems pull exhaust air from multiple locations in a building. The system is operated by a central fan that is connected to exhaust grilles via a duct network. These systems are used in high-rise apartment buildings. Exhaust grilles are typically located in kitchens and bathrooms, while outside air inlets are located in living and bedrooms. A dedicated range hood fan may also be needed to remove cooking odors and moisture at the source. This overall system configuration is especially beneficial in preventing interior water vapor from penetrating and condensing in the building fabric.

## Examining the Potential for Exhaust-Only Systems

- What airflow rate is needed?
- What is the best location for the exhaust grilles?
- Can you exhaust closest to the main pollutant source?
- Can multiple exhaust grilles use a single exhaust fan?
- Can pressures induced by the exhaust flows cause a spread of air pollutants, such as back-drafting or spillage from combustion appliances?
- Can residents either intentionally or unintentionally block the exhaust grilles?
- Will the noise of the exhaust fans bother residents?
- How should the flow be controlled—constant or intermittent, switch or timer?
- Where does supply air come from?
- Do corridors and hallways need exhaust ventilation?
- Is energy recovery an option?
- Are exhaust ventilation interactions with laundry facilities eliminated?
- Are existing ducts tight enough?
- Are the fans sized correctly to overcome pressure drops in ducts?
- Are the duct runs correctly sized, smooth, and straight?
- Is ductwork through unconditioned spaces (roof and sub-floor areas) avoided? Where such duct runs are necessary, is ductwork insulated and air tight?
- Do spot fans in bathrooms and kitchens (or elsewhere) need to be continuous or user-controlled?

## Limitations and Design Precautions

Potential benefits of exhaust ventilation must be weighed against the cost, operational energy, and long-term maintenance needs. If the building is too tight or there are insufficient supply air openings, either the suction pressure (hence, electrical energy costs) will rise or the fan will be unable to deliver the design air flow rate. High levels of under-pressure may cause unwanted noise and drafts as

well as cause combustion flues to backdraft, and may permit radon and other soil gases to enter the building. Therefore, excessive under-pressure must be avoided.

Strict controls usually apply to the installation of ducted exhaust systems in buildings fitted with combustion appliances, such as unvented space heaters, open fireplaces, and wood stoves. Canadian Standard CAN/CGSB-51.71-95 (1995) requires that for dwellings which have naturally-vented combustion appliances, the under-pressure should not exceed 5 Pascals.

### Mechanical Exhaust Ventilation

#### Advantages

- Controlled ventilation rates are possible
- Removal of pollutants at their sources reduce the risk of pollutants migrating into the rest of the occupied spaces
- The risk of moisture entering walls is reduced in non-humid climates
- Heat recovery from the exhaust air stream is possible

#### Disadvantages

- Capital cost is greater than natural ventilation
- Operational electrical systems (including associated energy costs) are required
- System noise can be intrusive
- Regular cleaning and maintenance is necessary
- Internal doors need to be undercut to allow air flow between the supply air inlets and the exhaust grilles.
- Backdrafting from flues is possible if naturally-vented combustion appliances are not properly separated from the living space and the exhaust grilles or fan locations
- Fixed air inlets may result in the ventilation rate being influenced by weather conditions
- Constant exhaust airflow regulators are needed to compensate for adjustments to individual air inlets.

## Mechanical Supply Ventilation Strategies (Supply-only Systems)

Mechanical supply-only ventilation systems bring outside air into the building. This process induces a positive pressure which displaces indoor air through purposefully-provided openings and or envelope-leakage sites. Care must be taken to ensure that the walls are well-sealed and that exhaust grilles, fans and or operable windows are located near areas of moisture generation such as kitchens and bathrooms. Supply systems can include air filtration and thermal conditioning provisions.

Mechanical central-supply systems typically are located on the roof and deliver air either to a central location on each floor or individually to each of the units. Shafts or ducts then supply air to the corridors on each floor. Supply air enters individual apartments through supply grilles in the wall or door, or, when air supply goes to a corridor, through door undercuts. While corridor supply is common in practice, it may be in violation of fire codes.

### Examining the Potential for Supply-Only Systems

- What flow rate is needed?
- Where are the best locations for the supply registers?
- Can the supply flows cause a spread of air pollutants, such as moisture and odor through the apartment or building?
- Can the supply registers be intentionally or unintentionally blocked by residents?
- Will the noise of supply fans bother residents? (Remotely-mounted fan systems will be less noisy)
- How should the flow be controlled—constant or intermittent, switch or timer?
- Where does the exhaust air go?
- Do corridors and hallways need supply ventilation?
- How is the supply air to be heated, cooled and filtered?
- Are low velocity supply inlets acceptable to occupants?
- When, where, and how much can outside air be brought directly into the apartments without pre-heating?
- Is ductwork through unconditioned spaces (roof and sub-floor areas) avoided? Where such duct runs are necessary, is the ductwork insulated and airtight?

Mechanically distributed supply systems provide ventilation air directly to each apartment, and in most cases, the air needs to be conditioned. The supply duct drops can be located at the exterior walls, or as part of a window unit, or can be ducted individually to each room. Still other systems are a combination of both central and distributed ventilation, where each floor has an individual supply system which then provides ventilation air to each apartment—either under the door or through a grille.

## Limitations and Design Precautions

Supply ventilation can inhibit the entry of pollutants and soil gases into a space and can minimize the risk of back-drafting. However, supply-only systems are not normally recommended for dwellings since there is a risk that indoor-generated water vapor can penetrate and condense in the building fabric. Supply ventilation strategies may work well in hot climates (hot/humid climates with supply dehumidification) and as long as intermittent bathroom and kitchen fans are used to remove indoor-generated water vapor. Extreme care is needed over the siting of air intakes to avoid drawing in outdoor pollutants from local

sources. Air intakes and supply dampers must not be obstructed or blocked.

### Mechanical Supply Ventilation

#### Advantages

- Outdoor air can be pre-cleaned and conditioned.
- Good air control is possible.
- Outside pollutants and soil gases are inhibited from entering the building through infiltration
- Flue back-drafting risk is reduced
- Unnecessary infiltration can be restricted, provided the structure is fairly airtight
- Supply dehumidification is possible, though at a higher first cost

#### Disadvantages

- Bathroom and kitchen exhaust fans and or operable windows are needed to remove moisture and pollutants
- Problems occur if air intake dampers are blocked or closed or if air intakes are located next to a pollutant source
- Energy recovery is not possible

### Mechanical Balanced Ventilation Strategies

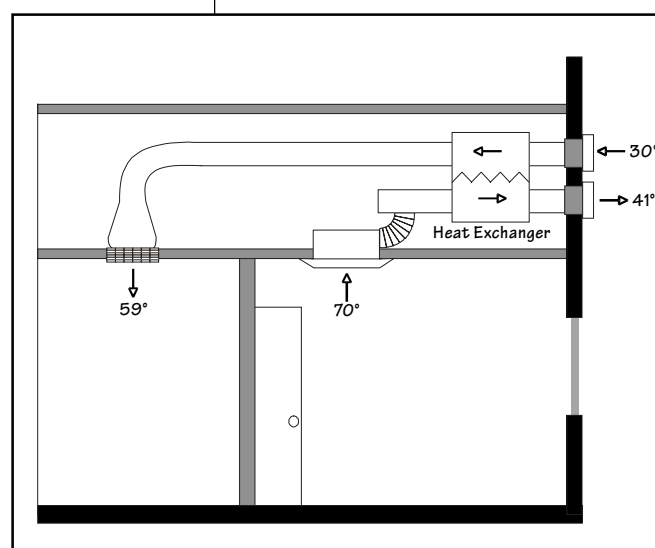
Balanced ventilation systems consist of separately ducted exhaust and supply systems. Typically, air is supplied and mixed into occupied zones and is exhausted from polluted zones. An air-flow pattern is established between the supply to the exhaust areas. Exhaust is supported by door undercuts or air transfer grilles between rooms.

The ideal balanced ventilation strategy reduces infiltration, minimizes interior airflows, and provides individually controlled supply and exhaust ventilation for each apartment. Sometimes, an intentional flow imbalance may be introduced to put the apartments in a slight negative pressure, and to reduce odor migration into the hallways. Balanced ventilation systems are popular in both high and low-rise dwellings, especially in severe climatic regions where worthwhile energy recovery is possible.

## Balanced Ventilation with Energy Recovery

Balanced systems can include air-to-air or air-to-liquid energy-recovery units, as depicted in Figure 15. This technology enables pre-conditioning of the incoming air. It is this potential for energy recovery that is often used to counteract the additional capital and operating costs. Waste energy from the exhaust air may be recovered and transferred to the incoming supply air stream using an air-to-air heat exchanger. An air-to-liquid heat pump can be used to recover between 20% to 40% of the waste heat or energy in the exhaust air for pre-heating of the domestic hot water. Up to 95% of hot water needs may be satisfied in this way.<sup>2</sup> Further energy may be recovered if used in conjunction with a hydronic central-heating system.

**Figure 15: Pre-conditioning Incoming Air with Energy Recovery Equipment**

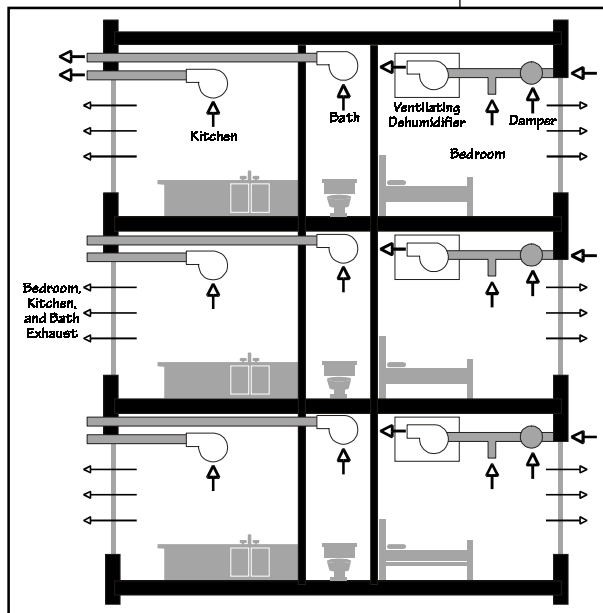


## Examining the Potential for Balanced Ventilation Systems

- How are the supply and exhaust flows balanced?
- Have stack effect and duct leakage issues been resolved?
- Is heat recovery ventilation cost effective, given the climate, usage patterns, and local energy rates?
- Is ductwork through unconditioned spaces (roof and sub-floor areas) avoided?
- Where such duct runs are necessary, is ductwork insulated and airtight?
- Do individual exhaust fans in bathrooms and kitchens (or elsewhere) need to be continuous or user-controlled?

<sup>2</sup> Knoll, 1992.

**Figure 16: Distributed Ventilation with Supply Dehumidification in Hot Humid Climates**



## Balanced Ventilation with Supply Dehumidification

In hot and humid climates, there is the additional need to eliminate moist air. Figure 16 shows a schematic of a ventilation strategy that includes supply dehumidification and distributed exhaust ventilation for moisture control. Supply dehumidification systems can have a high initial cost. However, installing supply dehumidification in the supply side of a central balanced ventilation system will be more cost-effective than installing individual supply dehumidification units in each apartment.

## Limitations and Design Precautions

Balanced systems are usually pressure neutral and are not resistant to infiltration driven by the effects of wind and temperature. As a consequence, the building, must be well sealed for optimum performance. Airtightness should be less than 1 ACH at 50 Pascals for

effective operation. Installing balanced systems in leakier buildings with higher air change rates will result in higher energy costs.

Balanced ventilation systems have both supply and exhaust fans, and generally consume more fan energy than a supply- or exhaust-only system. Adding energy recovery to a balanced ventilation system can save space-conditioning energy, which can be used to offset the higher fan energy costs.

## Balanced Mechanical Ventilation

### Advantages

- Energy recovery and pre-conditioning of supply air can save on energy expenditures
- Supply air is targeted to occupied zones
- Exhaust air is pulled from near pollutant sources (such as in kitchens and bathrooms)
- Supply air can be filtered and/or dehumidified

### Disadvantages

- Two systems are present, thus doubling installation and operational costs
- These systems require regular, long-term maintenance

The energy-related costs of space conditioning and fan energy must be taken into account when deciding whether energy recovery balanced ventilation is cost-effective. Balanced ventilation with energy recovery is usually not cost-effective in milder climates<sup>3</sup> due to the limited energy savings. Balanced ventilation with energy recovery is more cost-effective in more severe climates (cold, hot, and hot/humid climates). Enthalpic energy transfer can be used in hot and humid climates.

## Natural Ventilation

When designing natural ventilation strategies, the building permeability and ventilation openings are the key decision factors. The building structure should be airtight so that ventilation is confined to air flow through intentionally provided openings only. This condition permits more accurate design solutions and prevents air infiltration from interfering with ventilation performance. The philosophy, as with all ventilation strategies, is to “build tight and ventilate right.”

Natural ventilation is most suited for buildings located in mild to moderate climates away from inner city locations. Essentially, natural ventilation operates in “mixing” and pollutant “dilution” mode. It is possible, despite changing conditions, to design satisfactory natural solutions. However, for any given configuration of openings, the rate of natural ventilation varies according to the prevailing driving forces of wind and indoor/outdoor temperature difference.

## Natural Supply and Exhaust Techniques

Various techniques or combinations of techniques are used to provide natural ventilation; these include cross-flow and single-sided ventilation designs. These techniques both supply and exhaust air.

### Cross-flow Ventilation

Cross-flow ventilation relies on establishing a clearly defined, unimpeded air flow path between the incoming and outgoing air streams. Air should be supplied to and exhausted from areas of greatest activity within a building or apartment that passes through the zone of occupancy. Apartments with only one or two exterior orientations may have limited cross-flow ventilation. An “open-plan” interior is recommended to enhance cross-flow ventilation.

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<sup>3</sup> Milder climates have less than 2500 HDD

## Single-sided Ventilation

Sometimes ventilation design appears to be “single sided” in that the only obvious openings are positioned along just one side of the room. True single-sided ventilation, through a small opening, is driven by random turbulent fluctuations. At best, this type of single-sided approach is unreliable and is not recommended within a controlled natural ventilation strategy.

To take advantage of ventilation driven by the normal process of wind and stack forces, a large opening (large enough for air to flow simultaneously in and out) or more than one opening may be placed on a single side. For these configurations, flow rates may be calculated using standard network calculation techniques. Good spacing between openings is needed to generate reliable air change.

## Limitations and Design Precautions

Natural ventilation solutions must be robust enough to meet the indoor air quality and comfort needs under various temperature and pressure conditions. The minimum ventilation rate needed for satisfactory indoor air quality requirements and the maximum rate needed for summer cooling must be evaluated. Both needs should be matched against the corresponding prevailing driving forces so that the minimum and maximum opening areas of vents and windows may be determined. Ideally, the minimum need should be satisfied with permanent openings, while the maximum need should be met by adjustable openings.



## Natural Ventilation

### Advantages

- Suitable in mild or moderate climates.
- “Open window” environment is often popular
- Inexpensive compared to mechanical systems
- High air flow rates for cooling and flushing out the building are possible
- Short periods of discomfort
- Not space intensive
- Minimal maintenance
- Distributed natural ventilation systems are totally occupant controlled

### Disadvantages

- Airflow rates and the pattern of airflow are not constant
- Inadequate control over ventilation rates can exacerbate indoor air quality problems and heat loss
- Occupants may have to close natural ventilation openings in cold or hot conditions
- Excessive outside pollutants and noise can not be kept out without closing ventilation openings
- Some designs may present a security risk
- Heat recovery from exhaust air is technically feasible but not generally practicable
- Natural ventilation is hard to implement and generally not well suited for severe climates
- Changing airflow conditions require occupants to monitor and make changes to maintain comfortable ventilation
- Incoming air can not be filtered
- Natural ventilation strategies using ventilation shafts require large diameter ducts and are difficult to implement in existing buildings.



# Chapter 7: Operating and Maintaining Ventilation Systems



## Overview

Well maintained ventilation systems help ensure optimal performance, good indoor air quality, and energy efficiency. Experience suggests that the maintenance of ventilation systems is often inadequate and maintenance needs may even be overlooked at the time of building design. Examples of poor design and maintenance can be numerous: inaccessibility of system components, poor durability, and a lack of awareness of servicing needs have all contributed to reduced ventilation performance. In general, the building operator has no feedback regarding the performance of the ventilation system—other than complaints from tenants about discomfort.

## Operations and Maintenance Practices

A major benefit of preventative maintenance is efficient system operation. Preventative maintenance will increase energy efficiency, maximize equipment life and ensure optimum performance. Poor maintenance of mechanical ventilation systems clearly degrades long-term ventilation performance and efficiency.<sup>1</sup> Examination of buildings with mechanical ventilation systems have revealed that access to fans and filters for maintenance is often difficult, primarily due to inadequate planning.

Planning, without consideration of future maintenance requirements, can cause inaccessibility to the equipment that must be serviced. For example, in one system, filter replacement was impossible because access was prevented by a hot-water system installation. Sometimes, safety hazards exist. Frequently fans, filters, ducts, grilles, and vents are not cleaned, resulting in the deterioration of indoor air quality, as well as increased electrical power consumption, reduced air flow rates, and an imbalance in the ventilation system. In many cases, a poor system design results in unnecessary pressure losses in the ductwork, producing further

<sup>1</sup> Pallari et al., 1993

energy penalties. Ducts are often poorly fitted and/or joined and, in some cases, even are completely disconnected. Regardless of whether the building owner, the facility staff, or the occupant is responsible for system maintenance, the operation and maintenance instructions and other necessary tools are often unavailable.

Other examples of poor maintenance of ventilation systems also abound. Studies have found that the following deficiencies lead to health and safety problems in many buildings:

- Missing filters
- Ductwork caked with dirt and dust
- Entry of sewer gas into the HVAC system
- Rusted ductwork
- Fungal infestations
- Contaminated inlets
- Disconnected controls
- Slashed maintenance budgets
- Inadequately trained maintenance staff

## Design for Ease of Maintenance

Maintenance is essential to achieve reliable, cost-effective, and properly functioning ventilation systems that meet indoor air-quality needs. The best time to plan for maintenance requirements is during the design stage of a ventilation system. An increasing number of codes and standards focus on the ease of maintenance design.

## Maintenance Guidelines

Comprehensive guidelines have been developed to improve the design and maintenance of mechanical ventilation systems. Maintenance guidelines for ventilation systems have been produced by the Nordic Committee on Building Regulations (NKB, 1991). The guidelines include the following recommendations:

1. Controls shall be easy to reach, understand, and operate.
2. Components, which require maintenance, shall be located where they are readily accessible and replaceable.

3. Components should be mounted so that the work can be carried out easily and safely.
4. It shall be possible to clean both supply and exhaust ductwork systems in their entirety. Installations shall be cleaned often enough to ensure that neither the magnitude of airflows nor the quality of air is adversely affected by deposited dirt.
5. Components shall be made of materials that stand up to their intended use and maintenance; the choice of materials and construction techniques should not emit pollutants such as particles or gases which may adversely effect the quality of the supply air.
6. Rotary heat exchangers often have incorrectly fitted fans and dampers, such that as much as 50% of the exhaust air can be unintentionally recirculated via the supply air stream. In view of this, it has been recommended that installations shall have the required air tightness. Pressure conditions between supply and exhaust air installations shall be adjusted so that any unintentional flow from the exhaust air to the supply air is prohibited.
7. Ventilation systems shall be tested and balanced so that the intended flow rates and tolerances are obtained. When an installation is handed over to the owner and building operator, the installer shall demonstrate that it has been constructed and functions in the way intended. The installation shall be handed over in a clean state and ready for operation.
8. The necessary drawings and specifications shall be produced for a building and its ventilation installation. The materials to be used, including make and type designation, shall be documented. Air flow rates through individual rooms shall be specified. Instructions for the operation and maintenance of the ventilation installation shall be prepared and shall be available when the building is put into service.
9. Instructions that provide information on cleaning and maintenance shall be affixed near each terminal or appliance which is capable of being controlled by the building management or occupants. These instructions must be written in clear, precise language that does not rely on industry jargon to relay information.
10. Checks shall be made to ensure that the intended quality is secured at all stages of the design, construction, and operation of a building. Buildings shall be regularly inspected to ensure the correct functioning of the ventilation system and other systems which influence a good indoor environment.

## Maintenance of Specific Components

Reliable ventilation system performance depends on maintenance of the component parts. Major items include fans, air filters, ductwork and air distribution systems, air treatment components, and terminal units. It is essential that maintenance guidelines be provided for all of these items.

### Fans

There are a number of basic health and safety requirements associated with fan installations. For example, this equipment must be properly guarded to avoid unintentional access to rotating parts, and the power to the unit should be turned off and locked-out completely before any work is started. Bearings must be lubricated. Drive belts must be adjusted for tightness and alignment, and anti-vibration mounts must be checked. Fan impellers should be cleaned regularly to avoid build-up of dust and grease, especially when used to pull exhaust air from kitchens. Build-up of dirt on the impeller blades may cause unbalanced rotation that can result in excessive bearing wear and noise. It may also affect aerodynamic performance. Since mechanical damage or distortion of the impeller can also result in performance penalties, care must be taken during the cleaning of blades.

### Air Filters

Filters are a very important part of a ventilation system, and the grade of filter should be carefully selected upon consideration of the particle size range for particulates in the inlet air. Although using a lower filtration grade may lengthen the period of time available between filter changes, it will also result in reduced filter performance, potential indoor air quality problems, and staining on or near ceilings, walls, and grilles.

Good design and installation practices can reduce the demands on a filtration system. Positioning air inlets away from dirty or dusty areas will reduce the load. Ideally, inlet ducts should slope downwards towards the external louver, and the filter should be protected by bird and insect screens. To avoid pulling dust into the system, exhaust system grilles and openings should be sealed off until all construction work is completed.

No attempt should be made to clean and re-use filter elements unless specifically allowed by the manufacturer. Some systems use a measurement of

high differential pressure across the filter to indicate the need for replacement of the filter media. Regular visual checks should complement any pressure sensor readings to decide if filter replacement is necessary. On a roll-band filter, high pressure readings may result from too low a band speed. In another scenario, long-term low-pressure readings, rather than indicating that the filter is working satisfactorily, may instead reveal that the filter element is mechanically damaged and is not doing its job at all.

An accumulation of dust in the downstream ventilation system could result in an increased potential for the development of fungal spore and other microorganisms. It may also affect other components (e.g., dampers and the finned surfaces of coils), leading to an overall performance degradation. There may be an increased risk of fire, particularly if the air is grease-laden. This carryover of greasy, dirty air may also clog the automatic fire dampers and pose a significant safety risk.

Inevitably, used filters contain considerable amounts of dust, and therefore, precautions should be taken to minimize exposure to the dust hazards when handling or replacing them. Protective clothing and dust masks should be used.

## Ductwork

Major energy and air quality issues related to proper duct maintenance include maintaining the mechanical integrity of the ductwork (air-tightness and insulation), and the cleanliness of the duct internal walls. As mentioned previously, it is important to test for, and reduce duct leakage, as much as possible. Some duct sealing techniques include applying mastic or acrylic-backed metal tape to accessible duct leakage sites and or hiring an experienced contractor to perform aerosolized techniques to seal the leakage sites from inside the duct system.

Recently, duct cleaning has gained attention because of its role in providing healthy air to building occupants. When not properly filtered or cleaned, the ductwork provides a site for microbes or fungus to grow, which can release spores into the air. Changing filters regularly will greatly reduce the incidence of dirty ducts. Nevertheless, to minimize these risks, ducts should be cleaned by a nationally certified duct cleaning company. When cleaning ducts, maintenance personnel should withdraw sensors or probes to avoid damage. Similarly, special care should be taken with any dampers and damper linkages installed in the ductwork.

## Air-treatment Components

Like standard heating and air conditioning system components, ventilation system pre-heaters, pre-coolers, (de)humidifiers, and energy recovery units also require regular maintenance to operate at their rated performance levels. The ventilation system fans should be turned off when coils are cleaned so that dust is not carried into the ductwork and the occupied space. When cleaning coils and condensate pans, a sterilizing solution should be used. Drains should be kept clear, and the drain traps should be filled with clean water.

## Maintenance Principles

When establishing a maintenance protocol, it is important for the building owner/operator to establish the basic guidelines to be observed by a maintenance contractor or by on-site facility personnel. Relevant health and safety standards must be an integral part of any such protocol.

Planning scheduled maintenance to coincide with the least crucial demand periods on a ventilation system will save money and will minimize inconvenience to occupants far better than when the maintenance is conducted under a crisis situation. To employ this practice, system operators may need to collect data on fuel use, and plant running times. Monitoring the performance of ventilation components will help identify when system malfunctions may occur. Sudden changes in building fuel use patterns may indicate that the plant is malfunctioning, and provide a clue to the remedial action needed to avoid failure.

Management must decide whether “in-house” or outside assistance will be required to perform each task, and accordingly develop associated maintenance schedules. In any case, management must ensure that maintenance is carried out as scheduled, and to continually review whether changes in the maintenance program are required in the light of any changing circumstances.



## ASHRAE Standards

Many countries have introduced ventilation-related regulations, codes and standards. In the U.S., comprehensive ventilation, health, and indoor air-quality guidance is regularly produced and updated as part of ASHRAE Standard 62 (1989). The proposed revisions for ASHRAE Standard 62 address the maintenance of HVAC systems. The current draft suggests keeping up-to-date records and inspecting and maintaining:

- All major air handling components (visual inspection)
- Outside air dampers and actuators (annually)
- Ceiling return plenums (annually)
- Heating and cooling coils (annually)
- Drain pans (annually)

Further, flow rates should be measured and adjusted upon system renovation, or at least every five years, and filters should be replaced at least twice yearly.

## Implementing Maintenance Regulations and Standards

Maintenance guidelines are an important component of building performance and operations. For these guidelines to be effective, however, the adoption of the standards and regulations must be followed by their implementation and enforcement. Without this provision, one will continue to see the poor performance of ventilation systems and its resulting impact on the health and comfort of the occupants of apartment buildings.



# Appendix A :

## Apartment Building Ventilation Audit

### Apartment Building Ventilation Assessment Protocol

Before undertaking any investigation on ventilation in apartment buildings, it is important to identify what your goals are for the project. By clarifying your objectives, you can focus on the best ways to answer the questions. The list below gives examples of the types of questions that you may be asking.

- Are the apartments receiving adequate ventilation (based on ASHRAE 62) for the health and comfort of the occupants?
- How much reduction in energy consumption is possible through control of ventilation?
- How much reduction in energy demand is possible through control of ventilation?
- How cost effective are the retrofits?
- How much variation in supply ventilation is there between apartments?
- How much variation in exhaust ventilation is there between apartments?
- How much air leakage is there from the apartments to outside?  
To adjoining units?
- Can (and should) the natural ventilation be reduced by retrofit measures, e.g., weatherstripping corridor doors, elevator shafts, windows, etc.?
- Can the mechanical ventilation be controlled more efficiently?
- What practical advice can be given on what steps should be done to audit and retrofit these systems?

List other questions specific to your project.

## Apartment Building Ventilation Audit

### Basic Protocol

1. Interview building manager on history of building and maintenance activity (See Audit Sheet A).
2. Collect utility bills (gas, oil, and electric), building plans, mechanical ventilation diagrams, and any other written documentation on the building and its systems.
3. Building Walk-Through Measurements
  - a. Inspect mechanical rooms, roof-top equipment, elevator penthouses, and stairwells and other vertical shafts.
  - b. Using a flow hood to measure the supply air flows and temperatures at the registers in the hallways at several floors.
  - c. Measure corridor exhaust flows, if any (e.g., garbage chutes).
4. Measure the gap beneath corridor doors to apartments and staircases, or do a visual survey.
5. Measure the pressure differences between hallways and apartments.
6. Measure the pressure differences between hallways and staircases and hallways and elevator shafts at different floors.
7. Photograph building exterior and roof equipment.
8. Apartment Measurements
  - a. Measure the exhaust air flows in the kitchens and bathrooms of 4-6 apartments in each building. Each measurement takes about 1 hour per apartment. This will require notification of residents and scheduling unless there are empty apartments. (See Audit Sheets B and D).
  - b. Measure the air leakage of individual apartments, both to the outside and to adjacent units. This will require careful scheduling because you will need to have access to adjacent units simultaneously. These tests will take 1-2 hours, and you would like to make two tests in each building.
  - c. Survey tenants (See Audit Sheet C).

# Apartment Building Ventilation Audit

## Audit Sheet A: *Building Survey*

Building: \_\_\_\_\_ Auditor: \_\_\_\_\_

Date: \_\_\_\_\_ Time: \_\_\_\_\_

When was the building built?

How many stories?

How many units?

What type of construction is the building?

How is the building heated?

How is the building ventilated?

- Supply air heat source:
- Exhaust air:
- Controls: what schedules are the fans on?
- Are there ventilation grilles or openings in the apartment to the outside?

Are there problems with the ventilation system?

Are there tenant complaints with odors, noise, comfort or drafts from system?

What type of maintenance is conducted on the ventilation system? Filter changes?

What is typical window opening behavior of the tenants?

Do the tenants use the kitchen and bathroom exhaust ventilation?

Notes:

## Apartment Building Ventilation Audit

### Audit Sheet B: *Temperatures & Air Flows*

Building: \_\_\_\_\_ Auditor: \_\_\_\_\_

Date: \_\_\_\_\_ Time: \_\_\_\_\_

Outside Temperature: \_\_\_\_\_

Supply Register Size: \_\_\_\_\_ Exhaust Register Size: \_\_\_\_\_

<u>Floor</u>	<u>Temperature</u>	<u>Supply Air Flow</u>	<u>Exhaust Air Flow</u>
	[°F / °C]	[CFM]	[CFM]
1	_____	_____	_____
2	_____	_____	_____
3	_____	_____	_____
4	_____	_____	_____
5	_____	_____	_____
6	_____	_____	_____
7	_____	_____	_____
8	_____	_____	_____
9	_____	_____	_____
10	_____	_____	_____
11	_____	_____	_____
12	_____	_____	_____
13	_____	_____	_____
14	_____	_____	_____
15	_____	_____	_____

Notes:

# Apartment Building Ventilation Audit

## Audit Sheet C: *Tenant Survey*

Building: \_\_\_\_\_ Auditor: \_\_\_\_\_

Date: \_\_\_\_\_ Time: \_\_\_\_\_

Are you satisfied with the temperature in your apartment?

Are you satisfied with the ventilation in your apartment?

Is it ever too stuffy in your apartment?

Is it ever too drafty in your apartment?

Are you ever bothered by odors from neighboring apartments or from  
the corridor?

How often do you open windows?

In Winter:

In Summer:

How often do you run the fan in the bathroom?

How often do you run the fan in the kitchen?

Notes:

## Apartment Building Ventilation Audit

### Audit Sheet D: *Apartment Survey*

Building: \_\_\_\_\_ Auditor: \_\_\_\_\_

Date: \_\_\_\_\_ Time: \_\_\_\_\_

Apartment ID: \_\_\_\_\_

Apartment size (ft<sup>2</sup>): \_\_\_\_\_

Kitchen exhaust grille size: \_\_\_\_\_

Kitchen exhaust air flow: \_\_\_\_\_

Is there a separate exhaust fan in the range hood? \_\_\_\_\_

Bathroom exhaust grille size: \_\_\_\_\_

Bathroom exhaust air flow: \_\_\_\_\_

Do apartment windows seal tightly when closed? \_\_\_\_\_

Are there condensation problems on the windows? \_\_\_\_\_

If yes, how frequently? \_\_\_\_\_

Apartment sketch [optional]: \_\_\_\_\_



# Apartment Building Ventilation Audit

## Equipment List

- \_\_\_ Adjustable wrench
- \_\_\_ Blower door(s) and manometers
- \_\_\_ Camera and film
- \_\_\_ Digital thermometer
- \_\_\_ Door stops
- \_\_\_ Duct tape
- \_\_\_ Extension cords and “cheaters”
- \_\_\_ Flashlight
- \_\_\_ Flow hood
- \_\_\_ Hot-wire anemometer
- \_\_\_ Plastic sheet
- \_\_\_ Pressure sensors and tubing
- \_\_\_ Scissors
- \_\_\_ Screwdrivers (flat blade and Phillips)
- \_\_\_ Smoke sticks
- \_\_\_ Step ladder or step stool
- \_\_\_ Tape measure
- \_\_\_ Other equipment:



# Appendix B: Frequently Asked Questions

## 1. What are reasonable assumptions for air change rates in apartment buildings?

There are very few actual measurements of air change rates in apartment buildings, e.g., using tracer gases. However, the data suggest that, for low-rise apartments (frame and brick construction), the range of air changes is 0.5-1.5 ACH. The range of air changes is 0.2 to 1.0 ACH for high-rise concrete structures. Variables influence these rates both spatially and temporally.

## 2. What are the major variables which affect a building's air change rate?

The major variables related to air flow include the building's construction, mechanical ventilation systems, the wind speed and direction, and the temperature difference between inside and outside. The factors in the building's construction that are of importance are the degree of permeability to the outside, the connection between units, and the connection between the apartments and the vertical chases. While we can't generally change the wind and temperature differences, we can selectively reduce the leakage and change the mechanical ventilation.

## 3. What are the seasonal variations in a building's air change rate?

As both wind and temperature differences vary by season, a seasonal variation in a building's air change rate can be observed. In mild weather, there is a smaller stack effect, because more windows are likely to be open.

## 4. Is there a direct correlation between higher ventilation rates and higher fuel bills?

Yes. The cost of conditioning infiltration/ventilation air will vary from apartment to apartment, depending on building conditions, apartment location, etc. When looking at the energy use in high-rise apartments by floor, there is typically a drop in overall energy use for heating for apartments higher in the building. The exception is the top floor because it has increased heat loss through the roof. The simplest explanation is that the reduction in energy use is due to the reduced infiltration at the upper part of the building. Higher units may have greater heating needs due to greater winds, but the correlation due to stack effect is well documented.

**5. How much variation is there in ventilation rates from apartment to apartment?**

There are variations in ventilation rates from apartment to apartment due to stack effect, differences in the leakiness to the outside or elsewhere in the building and differences in occupant behavior. Individual window opening behavior can also lead to large differences in ventilation rates between apartments.

**6. What are the dynamics of air movement in specific apartments?**

The air moves around individual apartments due to temperature differences, mechanical fans, and flow paths. An exhaust fan in a bathroom will not provide ventilation for a bedroom when the doors are closed.

**7. How well do existing ventilation systems meet the indoor air quality needs of the residents?**

The conventional wisdom is that occupants will open windows to reduce odors and smoke. But several pollutants such as carbon monoxide and moisture vapor are invisible and odorless. Consequently, many apartment residents may not receive sufficient ventilation. Ventilation standards and codes cover the minimum recommended or required ventilation needed to avoid injury to health due to carbon dioxide, odors, and moisture. Values are largely prescribed according to building type, nature of pollutants, emission rates, and acceptable exposure levels. Requirements or recommendations may cover thermal comfort (e.g., ASHRAE Standard 55), odor intensity and the presence of drafts.

**8. How do you reduce the occupant discomfort from ventilation systems and drafts?**

In several cases, occupants may, due to discomfort, deliberately block ventilation by taping over registers and vents or by putting blankets or towels against a door that has a large undercut specifically for providing ventilation. Residents are frequently motivated to seal these intended supply routes because of the discomfort of cold drafts. But they also may seal them to shut out noise, light, insects, and odors from cooking or smoking. People experience discomfort from the movement of air depending on the temperature and velocity of the air and what part of the body experiences the drafts. Movement of air with a temperature below 70 °F can be experienced as discomfort. Heating supply air and or introducing it outside of the occupied zone will allow the supply air to mix with room air and minimize discomfort.

**9. What are reasonable ventilation design options for building owners when they upgrade existing buildings? Are there case studies on performance and costs?**

In some cases, the only work needed is to repair the existing ventilation system. Fans and motors need inspecting, filters need replacing, and the heating system for the supply air system needs to be checked to ensure proper operation. For buildings that have no mechanical ventilation, the options are more costly. In these cases, new exhaust fans can be installed and air inlets placed where needed.



# Glossary

## **ACCEPTABLE AIR QUALITY**

Air in an occupied space toward which a substantial majority [usually 80%] of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk [ASHRAE 62-89R].

## **AIR EXCHANGE RATE**

The amount of outdoor air entering a space in a given period of time (usually an hour) divided by the volume of the space. Usually expressed as “air changes per hour” or “ACH.”

## **AMBIENT AIR**

That portion of the atmosphere, external to buildings, to which the general public has access [EPA].

## **BUILDING ENVELOPE**

The exterior surfaces of a building—specifically, walls, roof, and floor (if over unheated basement, slab, or crawlspace).

## **CARBON MONOXIDE**

A colorless, odorless, toxic gas, formed as a by-product of incomplete combustion. Populations may be at risk at levels greater than 10 parts per million (ppm).

## **COMBUSTION APPLIANCE**

A fuel-burning (oil, gas, coal, or wood) device such as a range, furnace, or water heater.

## **DOUBLE-LOADED CORRIDOR**

A floor plan with apartments on both sides of a hallway.

## **ENERGY RECOVERY VENTILATION SYSTEM**

A device or combination of devices in which energy is transferred between the supply and exhaust air streams.

## **EXHAUST AIR**

Air discharged from any space to the outside by mechanical ventilation.

## **HEAT RECOVERY (see ENERGY RECOVERY VENTILATION SYSTEM)**

## **EXFILTRATION**

Air leakage outward through unintentional openings in walls, floors, or ceilings of a building to unconditioned space or the outside.

## **INFILTRATION**

Air leakage inward through unintentional openings in walls, floors, or ceilings from unconditioned space or from outside of a building.

## **MECHANICAL VENTILATION**

Ventilation provided by mechanically powered equipment such as motor-driven fans and blowers, but not by devices such as wind-driven turbine ventilators and mechanically operated windows.

## **NATURAL VENTILATION**

The movement of air without mechanical means into and out of an enclosed space through intentionally provided openings, such as open windows and doors.

## **SUPPLY AIR**

Outside air delivered by ventilation to a space.

## **VENTILATION**

The process of supplying or removing air by natural means (including infiltration) or mechanical means to and from a space for the purpose of controlling air contaminant levels, humidity, or temperature within a space.



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